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UNITED STATES
DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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# GYPSUM AND ANHYDRITE

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BY

FORREST T. MOYER

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# GYPSUM AND ANHYDRITE 1/

By Forrest T. Moyer 2/

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2/ Assistant mineral economist, Building Materials Section, Nonmetal Economics Division, Bureau of Mines.

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## INTRODUCTION

The usefulness of gypsum as a building material has been recognized from the time of the ancient Egyptians, but only within the last 25 years have the distinctive properties that adapt it to a great variety of processed products been recognized and widely utilized by a progressive industry.

The occurrence and uses of anhydrite and gypsum are so intimately related that the production, processing, and utilization of both minerals are discussed in this paper as parts of a single industry, which because of the vastly greater importance of gypsum will hereafter be termed the gypsum industry.

The intent of this paper is to describe the different methods of producing gypsum and anhydrite and processing them into their various products, as well as to give a general picture of the gypsum industry. The information presented herein is a condensed compilation of published data, supplemented by visits to gypsum plants in New York, Ohio, Michigan, Indiana and Virginia. Footnotes and a bibliography list publications in which more detailed information may be obtained.

## COMPOSITION AND PROPERTIES

Gypsum and anhydrite are both calcium sulphate minerals that differ chemically only in their water content; gypsum contains combined water and anhydrite does not. The physical properties, although similar, differ sufficiently to provide simple means for identification.

### Raw Gypsum

Pure gypsum may be broken down into its constituents as follows:

| | | | | |
|---|---|---|---|---|
| Gypsum ($CaSO_4.2H_2O$) = | Calcium sulphate ($CaSO_4$) | 79.1 percent | Lime (CaO) | 32.5 percent |
| | | | Sulphur trioxide ($SO_3$) | 46.6 percent |
| | Water ($H_2O$) | 20.9 percent | | |

Standard specifications (A. S. T. M. Designation C 22-25) state that a material shall not be considered gypsum if it contains less than 64.5 percent by weight of $CaSO_4.2H_2O$.

Pure gypsum is colorless to white, but various impurities change its color to shades of gray, brown, red, or pink. It has a hardness of 2 in the Mohs scale and can be scratched with the finger nail. The specific gravity of pure gypsum is 2.3 to 2.4, so that rock gypsum,



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free from moisture, weighs about 145 pounds per cubic foot. Gypsum crystallizes in the monoclinic system in tabular crystals that exhibit good cleavage (platy) parallel to the principal plane surface. The compressive strength, as determined by the Bureau of Standards on 6-inch cubes of Virginia gypsum, is:

3,224 lb. per sq. in. when dry and loaded on bed faces.
2,944 lb. per sq. in. when wet and loaded on bed faces.
2,617 lb. per sq. in. when dry and loaded parallel to bed faces.

Gypsum is slightly soluble in water, soluble in dilute hydrochloric acid, and insoluble in sulphuric acid. Its solubility in water is increased considerably by the presence of sodium or magnesium chloride.

Gypsum is widely useful because of its peculiar property of losing three-fourths of the combined water on application of moderate heat and its ability, when cooled and made plastic by admixture with water, to be spread, cast, or molded to any desired surface or form and finally to resume its original state by "setting." The heating process is known as calcining and the resulting product as calcined gypsum.

## Calcined Gypsum

Calcined gypsum, also known as plaster of paris, cement plaster, and erroneously "stucco", is obtained by heating raw gypsum so as to drive off most of the water of crystallization. The quantity of water removed, which determines the properties of the product, is governed by the fineness and purity of the raw material and by the time and temperature of calcination. In commercial practice gypsum is transformed through the following forms: Between 115° and 125°C. (235° and 260°F.), to hemihydrate; between 175° and 195°C. (350° and 385°F.), to soluble anhydrite; and, roughly, above 200°C. (395°F.), to insoluble anhydrite, although there is no definite transition temperature for the last change. Hemihydrate, the chief constituent of first-settle plaster, recombines readily with water and "sets." Its chemical composition is $CaSO_4.1/2H_2O$ (93.8 percent $CaSO_4$; 6.2 percent $H_2O$). Soluble anhydrite, the main ingredient in second-settle plaster, is an unstable, hygroscopic form with the composition $CaSO_4$. It reverts rapidly to the hemihydrate. Insoluble anhydrite or dead-burned gypsum (anhydrous calcium sulphate) does not recombine readily with water and sets very slowly or not at all. Calcination of gypsum to any of the above forms results in a volume shrinkage which in hemihydrate or first-settle material is approximately 16 percent and in soluble anhydrite or second-settle material approximately 20 percent.

First- and second-settle calcined gypsum set in the presence of water with evolution of heat and slight expansion. One theory of setting is that the unstable hemihydrate dissolves in the mixing water to produce a supersaturated solution from which the stable hydrated gypsum is precipitated in typical needlelike crystals. These crystals



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interfinger as they grow larger and bind themselves together to form a solid, relatively hard mass familiar to most people as hard wall plaster or set plaster. A second theory has been advanced that the hemihydrate first forms a gel or adsorption complex with the mixing water which is followed by the formation of gypsum crystals from the adsorption complex to result in set plaster. The apparent expansion during setting is about 0.1 to 0.2 percent.

## Anhydrite

Anhydrite may be broken into its constituents as follows:

Anhydrite ($CaSO_4$) = { Lime (CaO) 58.8 percent. ; Sulphur trioxide ($SO_3$) 41.2 percent. }

Although anhydrite contains no water of crystallization it is so similar to gypsum that under certain conditions it will change into gypsum, while under other conditions gypsum will revert to anhydrite. Anhydrite is commonly white, has a hardness of 3 to 3.5 in the Mohs scale, and has a specific gravity of 2.9 so that a cubic foot of anhydrite weighs about 180 pounds. It usually appears compact and granular, although fibrous masses and orthorhombic crystals are found which have good cleavages. Anhydrite is slightly soluble in water and soluble with difficulty in dilute hydrochloric acid. It is less soluble in water than gypsum but behaves in the same manner.

## ORIGIN

As gypsum and anhydrite deposits have the same origin, they will be discussed together as calcium sulphate deposits. These deposits may be grouped by origin as follows:

A. Precipitated from solution:

1. In sea water.
2. In inland- or desert-lake water.
3. In underground water.

B. Precipitated by chemical alteration of lime-bearing minerals.

C. Formed by disintegration and mechanical reaccumulation.

The theory of the origin of calcium sulphate deposits by precipitation from saline solutions (sea and inland lake waters) is not settled owing to the difficulty of accounting for the great thicknesses of some deposits and the peculiar association of calcium sulphate and other saline and nonsaline minerals. The "bar" theory, developed by the



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German chemist, Ochsenius,[3] and later modified by Branson[4] into a "modified-bar" hypothesis, concerns the formation of the deposits by evaporation of sea water in separate basins. The "desert" theory advanced by Walther[5] and, more recently, by Grabau[6] concerns the formation of thick deposits by the concentration by leaching of the connate salts originally enclosed in marine sediments in desert basins.

Ground water moving through calcium sulphate-bearing strata may take the sulphate in solution and later, under other conditions, redeposit the material in veins or beds or in efflorescent crusts. Gypsite and vein deposits are formed in this manner.

Limestones and lime-bearing minerals may be acted upon by water containing sulphuric acid or another sulphate in solution to form deposits of calcium sulphate.

Calcium sulphate sands, formed by the disintegration of existing deposits of gypsum or anhydrite, may be transported and concentrated by winds into drifts and dunes.

## RELATION OF GYPSUM AND ANHYDRITE

As shown by Van't Hoff, when a solution of pure calcium sulphate in water is evaporated at a temperature below 66° C. gypsum is deposited; above 66° C., anhydrite is deposited. The presence of other soluble salts, particularly sodium and magnesium chlorides and sulphates, in the solution lowers this critical temperature so that in the evaporation of sea water, the lower temperature limit of anhydrite deposition is 25° C. As this temperature is well within the reach of surface water in semiarid climates during periods of intense evaporation, it is probable that most of the calcium sulphate deposits were originally laid down as anhydrite. However gypsum, not anhydrite, is the stable form of calcium sulphate at atmospheric pressure and temperature and in the presence of moisture. Consequently there is a slow change from the original anhydrite to gypsum by hydration of the deposits lying at shallow depths in the zone of circulating ground water. This condition has been found in numerous localities and has led to the establishment of three vertical zones applicable to gypsum deposits derived from the hydration of anhydrite. Theoretically, the upper zone would contain only gypsum, the intermediate or transition zone an intimate mixture of anhydrite and gypsum in which hydration

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3/ Ochsenius, C., Bildung von Steinsalzlagern: Chem. Ztg., vol. 2, 1887, p. 846.

4/ Branson, E. B., Origin of Thick Gypsum and Salt Deposits: Bull. Geol. Soc. Am., New York, 1915, vol. 26, pp. 231-42.

5/ Walther, J., Gesetz der Wustenbildung: Quelle & Meyer Co., Leipzig, 1924, 421 pp.

6/ Grabau, A. W., Geology of the Non-Metallic Mineral Deposits: McGraw-Hill Co., New York, 1920, pp. 116-154.



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is active, and the bottom zone only anhydrite. Dyer[7] gives vertical depths based on well records in the Ontario (Canada) deposits as 0 to 225 feet for the upper zone, 225 to 275 feet for the transition zone, and 275 feet or more for the bottom zone. Surface conditions and type of over-burden determine the zone depths so that in each locality these limits will differ and have local variations. Bailey[8] uses top, bottom, side, and interior hydration to explain occurrences of anhydrite beds lying between gypsum beds. Not all gypsum deposits, however, were formed by alteration of anhydrite; some were originally deposited as gypsum.

## VARIETIES

The different forms in which gypsum occurs have been given specific names. Although there are similar varieties of anhydrite, they are not named but are simply called anhydrite, qualified by the principal characteristic of the variety, such as massive anhydrite, fibrous anhydrite, etc.

Gypsum occurs in the following forms:

Rock gypsum. - The most important commercial variety, rock gypsum, is opaque, granular, and massive and occurs interbedded with sedimentary rocks.

Alabaster. - A fine-grained, white, slightly translucent rock gypsum, suitable for sculpturing, is known as alabaster.

Gypsite. - Earthy gypsum, or gypsite, consists of an abundance of small gypsum crystals scattered through clay or sandy loam and forming up to 90 percent of the mass.

Selenite. - The crystalline gypsum, selenite, shows platy cleavage and is colorless. It usually occurs as distinct crystals or clusters of crystals.

Satin spar. - The fibrous variety of gypsum, occurring in veins and having a satiny or pearly luster and a fibrous fracture, is known as satin spar.

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7/ Dyer, W. S., Geology of Gypsum Deposits of Southwestern Ontario: Ontario Dept. of Mines, 34th Ann. Rept., vol. 34, pt. II, 1925, p. 58.

8/ Bailey, H. B., Hydration Factors in Gypsum Deposits of the Maritime Provinces: Am. Inst. Min. and Met. Eng., Tech. Pub. 308, 1930, pp. 4-5.



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## DEPOSITS IN THE UNITED STATES

More is known concerning gypsum than anhydrite because the prevalence of gypsum at the surface and its economic uses have led to its exploitation. However, the two minerals usually occur intimately associated in bedded deposits, and with increased cover or depth of operations the form of calcium sulphate to be expected is anhydrite. Recent researches on anhydrite, which is regarded as a detrimental impurity in gypsum, indicate that industrial applications for the mineral are increasing.

Gypsum deposits of good quality and commercial size are so widespread in the United States that the development of a deposit depends largely upon the demand for gypsum and gypsum products in the immediate region of the particular deposit.

### Arizona

Gypsum deposits of commercial size and quality occur in Cochise, Pima, and Pinal Counties in southeastern Arizona, Navajo County in east-central Arizona, and Mohave County in the northwestern corner of Arizona. Only a few of the deposits have been developed because of the small demand for gypsum products within the market area. The only active operation at present is working gypsite and rock gypsum near Douglas, Cochise County. Deposits in the Santa Catalina Mountains, Pima County, and near Winslow, Navajo County, have been worked intermittently.

### California

Gypsite deposits, most of which are small, occur through most of the coast ranges of California, particularly south of San Francisco Bay. They have been quarried periodically in Fresno, Kern, King, Los Angeles, Merced, Riverside, San Benito, and San Bernardino Counties.

Extensive deposits of rock gypsum are found in Imperial, Inyo, Riverside, and San Bernardino Counties. Smaller deposits have been worked in Fresno, Orange, Santa Barbara, and Ventura Counties. Gypsum beds over 200 feet thick occur in Imperial County north of Plaster City and Maria. In Riverside County a belt of steeply dipping gypsum beds 10 to 100 feet thick extends through the Palen and Maria Mountains where they have been worked. In the Avawatz Mountains, San Bernardino County, rock gypsum beds up to 10 feet thick outcrop over a large area. Near Acme, Inyo County, several gypsum beds 6 to 10 feet thick have been worked along outcrops.

### Colorado

Extensive deposits of rock gypsum are found in the western half of Colorado, notably in Larimer, Jefferson, Douglas, El Paso, Pueblo, Fremont, Eagle, Pitkin, Garfield, Rio Blanco, Delta, Montrose, San Miguel,



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and Dolores Counties. Gypsite occurrences usually are small and are closely associated with outcrops of rock gypsum. Some gypsite has been quarried near Stone City, Pueblo County, and Coaldale, Fremont County. Active operations are located on large deposits of rock gypsum near Arkins, Larimer County, and Howard, Fremont County.

Recently, alabaster of good quality has been obtained from the rock-gypsum beds in Larimer County. The material is dense and compact, has a banded or mottled appearance, and takes a high polish. It is used for making small, carved art objects.

## Idaho

Rock-gypsum beds of workable size are reported to outcrop in Washington and Bear Lake Counties. Gypsum of good quality is mined 18 miles southeast of Leadore, Lemhi County.

## Iowa

A flat-lying gypsum bed of high quality, which is 10 to 30 feet thick and underlies a large area near Fort Dodge, Webster County, has been developed for a long time. Several mud or otherwise impure bands, vertical joints, and solution channels are the only irregularities in the bed. Near Centerville, Appanoose County, a gypsum bed 10 to 22 feet thick, lying 550 feet below the surface, was worked from 1917 to 1935. Anhydrite is a common associate. Because of the depth and the large amounts of artesian water the bed was difficult to mine.

## Kansas

In the vicinity of Blue Rapids, Marshall County, a large area is underlain by a nearly flat-lying bed of gypsum 8 to 9 feet thick that has been worked extensively. Rock-gypsum beds 5 to 14 feet thick have been worked intermittently in southern Dickinson, northern Marion, and eastern Saline Counties, where they occur in two distinct horizons. In southern Kansas a series of gypsum beds 3 to 25 feet thick extends westward from Medicine Lodge, Barber County into Comanche County and southward into Oklahoma. The beds are easily accessible and have been quarried for a number of years.

Small deposits of gypsite several acres in extent and up to 18 feet thick are found chiefly in the central part of the State. Most of them have been worked out.

## Michigan

Large deposits of rock gypsum occur at many places in a nearly continuous belt of strata that outcrop around the coal basin occupying the central part of the Southern Peninsula. Areas developed commercially



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are in Kent, Iosco, and Arenac Counties. In Kent County a series of gypsum beds 6 to 20 feet thick outcrops in a belt from Grand Rapids into eastern Ottawa County. Four of the beds have been developed extensively by quarrying and underground mining.

A gypsum bed 18 to 23 feet thick at Alabaster extends over a large area in southeastern Iosco County and northwestern Arenac County. Drill holes near Alabaster show five or more gypsum beds 4 to 22 feet thick lying below the bed quarried. Near Turner, Arenac County, a bed of commercial thickness lies above the Alabaster quarry bed. Gypsum outcrops extensively on the St. Ignace Peninsula and adjacent islands in Mackinac County.

## Montana

Large deposits of rock gypsum occur in Montana, but they have been developed only in Cascade, Fergus, and Carbon Counties. The Cascade County deposits are in lenticular beds up to 15 feet thick. Gypsum is mined at Heath, Fergus County, from a bed 9 to 14 feet thick and near Hanover, in the same county, from beds up to 7 feet thick. In Carbon County gypsum beds from 10 to 50 feet thick have been explored occasionally. Extensive outcrops of thick gypsum beds are reported in Big Horn and Madison Counties.

## Nevada

Thick beds of exceptionally pure rock gypsum outcrop in the western and southern parts of the State. The western area lies in Humboldt, Washoe, Pershing, Lyon, and Mineral Counties, where the gypsum has been developed commercially near Lovelocks, Gerlach, Mound House, Ludwig, and Mason. The beds of this area have thicknesses up to 200 feet, have more or less steep dips, and are associated with limestone. The deposits of the southern area, where beds up to 300 feet thick are found in Clark and Lincoln Counties, have been worked at Arden, Las Vegas, and Moapa. Thick outcrops of gypsum are reported in the bluffs of the Virgin River.

Small deposits of gypsite up to 15 feet thick occur near rock-gypsum outcrops but have been utilized only in the Mound City region.

## New York

Workable beds of rock gypsum outcrop in a belt extending from Madison County westward through the intervening counties into Canada just north of Buffalo. The belt is 12 miles wide at Syracuse, Onondaga County, and 20 miles wide at Seneca Falls, Seneca County, and it averages 7 to 10 miles in width through the remaining distance to Buffalo. Gypsum deposits vary in quality and quantity throughout this area, but deposits of high-grade material (ower 90 percent) are



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reported to be limited to several counties in the western section. Eastward the gypsum contains increasing amounts of interbedded thin shale and limestone bands. The gypsum beds range in thickness from an average of 4 or 5 feet in the western part to a maximum of 30 or 40 feet near Syracuse. The increase in thickness is accompanied by a decrease in purity.

The gypsum beds have a southerly dip of 20 to 50 feet per mile, and as the depth of cover increases anhydrite is found. The vertical depth to the upper limit of the anhydrite zone ranges from 100 to 200 feet depending upon the character of the overlying rock.

At present the gypsum is produced by underground mining in the western half of the belt near Akron and Clarence Center in Erie County, Alabama and Oakfield in Genesee County, Garbutt and Wheatland in Monroe County, and Victor in Ontario County.

## Ohio

Gypsum deposits have been developed only in the northwestern part of the State, in Ottawa and Erie Counties. There are active operations near Port Clinton and Gypsum in Ottawa County where the gypsum occurs in three beds ranging from 5 to 15 feet in thickness. In Erie County near Castalia, a 12-foot bed of gypsum, some of which has been classed as alabaster, has been mined intermittently.

## Oklahoma

Extensive deposits of rock gypsum associated with anhydrite occur in three general areas in the western part of the State. The first area is a line of gypsum hills along the Cimarron River, extending from Canadian County through Blaine, Major, Woodward, Woods, and Harper Counties into Kansas. Three beds 3 to 20 feet thick occur in these hills. The second area extends as a series of low knolls and ridges from Stephens County through Comanche, Grady, Caddo, Washita, and Custer Counties into Dewey County. Important deposits lie in Custer and Washita Counties where beds 40 to 60 feet thick are traceable for several miles. The third area is in the southwest corner of the State in Jackson, Harmon, Greer, and Beckham Counties, where five beds 18 to 25 feet thick in places are reported. There are active gypsum operations near Ideal, Southard, and Watonga, Blaine County, and near Eldorado, Jackson County.

Gypsite deposits are common in the three described areas, but most of them are small except in Jackson County where deposits up to 400 acres in extent and up to 12 feet in thickness occur.



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## South Dakota

An elliptical outcrop of gypsum-bearing strata extends around the Black Hills in the so-called Red Valley formed by the Spearfish formation. Beds of commercial quality range up to 30 feet in thickness, and some are continuous for long distances. The only active operation is near Piedmont, Meade County, but formerly gypsum was produced near Hot Springs, Rapid City, Black Hawk, and Sturgis. Some gypsite deposits, associated with the rock-gypsum outcrops, attain workable size.

## Texas

The three principal gypsum-bearing areas of Texas are: (1) The north-central part extending from Nolan County into Hardeman County; (2) the west part in Hudspeth and Culberson Counties; and (3) the southern and southeastern parts of the State. The north-central belt, which outcrops over an area 20 to 50 miles wide and 150 miles long, is a continuation of the gypsum beds of southwestern Oklahoma. It contains a number of gypsum beds up to 60 feet in thickness. The beds of Culberson and Hudspeth Counties outcrop over large areas and are up to 300 feet thick. In southeastern Texas great thicknesses of gypsum have been reported at depth in oil wells. In Brooks County near Falfurrias a remarkable deposit of selenite, consisting of transparent layers, is said to be over 1,000 feet thick.

Commercial-grade gypsite deposits are commonly associated with the rock-gypsum outcrops. Many of the gypsum plants utilize both materials. There are active gypsum operations near Falfurrias in Brooks County, Longworth and Rotan in Fisher County, Sweetwater in Nolan County, and Acme in Hardeman County. Other plants have operated sporadically in all of the gypsum-bearing belts.

## Utah

Gypsum deposits occur in the central and southern parts of the State. Near Nephi and Levan, Juab County, deposits of massive gypsum are 250 to 300 feet thick, and three beds 10 to 50 feet thick outcrop almost continuously from Manti, Sanpete County, to Sigurd, Sevier County. In Emory and Wayne Counties several thick gypsum beds are reported to contain alabaster. A gypsum bed 175 feet thick outcrops from Iron County into Kane County. Other deposits occur in the southern half of the State. Anhydrite is present in the gypsum at Nephi and Levan and is reported from several other localities. Active operations are located near Nephi and Levan, Juab County, and Sigurd, Sevier County.



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## Virginia

Workable gypsum deposits are found in a narrow belt about 16 miles long in the valley of the North Fork of Holston River in Washington and Smyth Counties. The gypsum occurs as steeply dipping large masses or lenses that attain thicknesses of 50 feet. In places salt is associated with the gypsum. Anhydrite is usually present. Gypsum mines are operated near North Holston, Smyth County, and Plasterco, Washington County.

## Wyoming

Gypsum deposits are widespread in the eastern half and the central and north-central parts of the State. More than 800 miles of gypsum-bearing formations are exposed, and throughout this extent gypsum beds of commercial grade up to 20 feet thick are generally present. Gypsite deposits abound in close association with the rock-gypsum outcrops. The only active plant is a gypsite operation near Laramie. In the past other plants have worked both gypsite and rock gypsum near Laramie, Albany County, and Greybull, Big Horn County.

## Other States

Formerly gypsum was obtained from extensive deposits in New Mexico and from rather limited deposits in Alaska and Oregon. Occurrences of possible commercial value are reported in Arkansas, Florida, and Louisiana.

## FOREIGN DEPOSITS FROM WHICH CRUDE GYPSUM IS IMPORTED

Crude gypsum for processing into products is imported into the industrial Atlantic Coast States from extensive deposits in the Provinces of Nova Scotia and New Brunswick, Canada. It is also imported into California from a deposit on San Marcos Island, Baja California, Mexico, and into Arizona from the adjoining State of Sonora, Mexico. Imports from Italy consist chiefly of alabaster which is quarried in the Communes of Santa Luce and Castellina Marittima.

## USES OF GYPSUM

Gypsum is used both raw and calcined. In recent years 25 to 30 percent of the total supply (domestic production and imported material) of gypsum in the United States has been sold for use in the raw condition. Crude material for use in this form is prepared by crushing and grinding, the degree being determined by the destined use. Standard specifications (A. S. T.M. Designation C 22-25) provide for the following size groups of raw gypsum:



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Crushed gypsum - Material which shall all pass a 3-inch ring and not more than 25 percent shall pass a No. 100 sieve.
Sized gypsum - Material which shall all pass a 1-1/2-inch ring and not more than 10 percent shall pass a 1/4-inch sieve.
Ground gypsum - No. 1, material which shall all pass a No. 14 sieve and not less than 85 percent shall pass a No. 100 sieve.
No. 2, material which shall all pass a No. 14 sieve and not less than 60 percent nor more than 85 percent shall pass a No. 100 sieve.
No. 3, material which shall all pass a No. 8 sieve and not less than 40 percent nor more than 60 percent shall pass a No. 100 sieve.
No. 4, material which shall all pass a No. 100 sieve.

For use in the calcined state the crude material is prepared by crushing and grinding, followed by calcination and sometimes by further grinding.

## Raw or Uncalcined

Retarder for Portland Cement. - Raw gypsum is universally employed to retard the set of portland cement, and this use in 1937 represented 89 percent of the total sales of raw or uncalcined gypsum. Cement producers purchase gypsum for retarding purposes on the basis of its sulphur trioxide ($SO_3$) content, generally specifying that it be between 36 and 42 percent, which corresponds approximately to rock gypsum 75 to 90 percent pure. It is important that gypsum for this use should be uniform in analysis, otherwise the initial and final setting time of the cement will vary. Because excessive quantities of gypsum are detrimental to the cement, the standard specifications of the American Society for Testing Materials limit the content of sulphur trioxide in portland cement to 2 percent by weight. The crude gypsum is prepared for use as a retarder by crushing it to a coarse size (generally minus 1 1/2-inch) and screening it if a clean, sized material is desired. It is then added to the cement clinker before final grinding. Calcined gypsum as the retarding agent is preferred by a few cement mills, although the cost is considerably higher.

Fertilizer or Land Plaster. - Ground gypsum has been used as fertilizer or "land plaster" in Europe since the middle of the eighteenth century and in the United States since the end of the same century. In the past 20 years experiments by agricultural authorities have shown that gypsum acts both as a direct and indirect fertilizer and is beneficial to soils in mechanical ways. As a direct fertilizer gypsum is said to be a source of sulphur trioxide which is an essential food for plants such as cereals, hays, legumes, cotton, tobacco, peanuts, etc. Indirectly gypsum provides plant food by the liberation of soluble potash in usable form following its reaction with insoluble potash silicates and by stimulating the growth of nitrogen-fixing bacteria in the soil, thus increasing the supply of available nitrogen.



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Gypsum is beneficial to soils containing injurious salts by counteracting, to some extent, their harmful effects. It is regarded as a specific for black-alkali soils in which it reacts with the deleterious sodium carbonate to form calcium carbonate and sodium sulphate. Gypsum acts as a preservative and sanitary agent when sprinkled over stable manure by changing the volatile ammonium carbonate into nonvolatile ammonium sulphate, thus retaining the nitrogen and checking the decomposition of the organic materials and humus in the manure. Mechanically gypsum is reported to be beneficial to tough clay soils by breaking them into less-compact particles and to sandy soils by retaining moisture and drawing additional moisture from the air through the strong affinity of ground gypsum for water.

Fillers. - Crude gypsum, selected for its whiteness and finely ground to a flour and screened, is used for many purposes such as filler for paper, textiles, paint, buttons, poker chips, phonograph records, and blasting powder. Because gypsum is neutral it is a desirable inert material for chemicals and is used as a diluent in various insecticides and drugs. Finely ground gypsum is also used to condition brewer's water and as the chief constituent of blackboard chalk.

For Ornamental Stone. - The fine-grained translucent variety of gypsum known as alabaster is used for statuary, novelties, and decorative purposes.

Flux. - Raw gypsum is used as a flux in smelting certain New Caledonia nickel ores, in the concentration of lead-copper matte in reverberatory furnaces, and in the Carmichael-Bradford blast-roasting process for treating galena concentrate.

Sulphide, Sulphate, Lime, and Cement Manufacture. - Although gypsum is not utilized in the United States for the manufacture of other sulphides and sulphates, lime, and cement, it is reported to be used in large quantities for these purposes in certain European countries. During the World War Germany first used gypsum as a raw material for the manufacture of sulphuric acid. Of the many processes patented and used, the most successful consists of heating a mixture of gypsum, clay, and coal and adding sand and slag to form sulphur dioxide gases and a portland-cement clinker. The gases are purified and turned into sulphuric acid. Other patents cover processes for the conversion of gypsum mixed with coal, coke, clay, or other substances into calcium sulphide, sulphur, sulphur dioxide, and lime. Commercial plants in Germany, France, and the United Kingdom utilize, in connection with the Haber process, the chemical principle of double decomposition to produce ammonium sulphate from gypsum, ammonia, and carbon dioxide. The ammonium sulphate may be treated further with sodium nitrate to produce ammonium nitrate.



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A recent United States patent covers the use of gypsum as a substitute for salt cake in the glass batch. It is claimed that the evolution of the combined water in the gypsum assists in clearing the glass melt.

## Calcined

Gypsum that has been heated enough to be partly dehydrated is known as calcined gypsum or plaster of paris and has approximately the chemical formula $CaSO_4.1/2H_2O$. Standard specifications[10] state that calcined gypsum, after it is mixed with water and the paste allowed to set, shall have a tensile strength of not less than 200 pounds per square inch and a compressive strength of not less than 1,000 pounds per square inch. The product of heating or calcination is also commonly called "stucco" within the gypsum industry, but this is a misnomer and should be avoided. Calcined gypsum without further preparation has limited use, but when it is ground and minor amounts of other substances are added as accelerators, retarders, fillers, and binders its uses are varied and extensive and may be divided roughly into those for manufacturing and those for building purposes.

### Manufacturing Uses

Calcined gypsum is prepared for manufacturing uses by grinding and the addition of accelerator or retarder as required. It is employed chiefly to make molds and casts and to hold articles for polishing.

Plate Glass and Other Polishing Beds. - Calcined gypsum intended for use to hold glass during polishing must be finely ground and free from grit in order not to scratch the glass embedded in it. The rough plates of glass are placed on a table which has been covered with a slurry of plaster of paris. When the plaster sets it holds the plate firmly and relieves the glass from strain during polishing. For polishing the other side the plate is broken loose and reset on the table, using new plaster. With the introduction of continuous polishing machines the quantity of gypsum plaster used for this purpose has decreased greatly.

Calcined gypsum is used similarly to hold precious stones or metals for polishing or engraving. In the ornamental-stone industry a slurry of gypsum plaster is used to fill the cracks between individual stones that are to be polished. The plaster prevents the loss of abrasive.

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10/ American Society for Testing Materials, Standard Specifications for Calcined Gypsum (Designation C 23-30).



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Molds. - Calcined gypsum has several properties that make it an excellent economical material for molds used in the manufacture of other articles. It has a quick set that is subject to close control, and when setting it expands slightly to yield accurate, detailed reproductions of the original article. The plaster mold is also rigid, strong, porous, and of light weight. If porosity is not desired it is easily overcome by painting or covering the mold surface with a nonporous material. Large quantities of gypsum plaster are used to manufacture pottery and terra-cotta molds; for these purposes the porosity of the mold is an advantage. Standard specifications for gypsum plaster (A. S. T. M. Designation C 60-30) used for the manufacture of pottery molds state that is shall contain not less than 90 percent by weight of calcined gypsum ($CaSO_4.1/2H_2O$), shall all pass a No. 30 sieve and not less than 94 percent a No. 100 sieve, shall set in not less than 20 or more than 40 minutes, and shall have a tensile strength after setting of not less than 250 pounds per square inch. Gypsum plaster is also used to make molds for rubber stamps, hat manufacturing, and art and scientific work. Molds for nonferrous metal castings are prepared by mixing molding plaster with a refractory material.

A special molding plaster made by a patented process is manufactured by calcining gypsum in an autoclave under pressure, fine grinding, and mixture with other ingredients. It sets with a hard, dense finish, has a compressive strength of 7,500 pounds per square inch, and has an expansion that can be controlled.

Casting Material. - Calcined gypsum is widely used as a casting material for reproductions because it expands slightly when setting and fills the mold perfectly. Cast statues, ornaments, relief maps, and other art and scientific objects are made of gypsum plaster. Dental plaster is a specially selected and prepared plaster of paris used to form casts for dental-plate work. According to standard specifications for dental plaster (A. S. T. M. Designation C 72-30), it is classed by time of set into three grades, Q, M, and S, which set respectively between 2 and 4, 6 and 12, and 20 and 40 minutes. The specifications also state that dental plaster shall contain not less than 93 percent calcined gypsum, that it shall all pass a No. 30 sieve and not less than 95 percent a No. 100 sieve, and that its tensile strength after setting shall be not less than 300 pounds per square inch.

Drying Agent. - Calcined gypsum, prepared by careful heating for 3 hours at approximately 240° C. (460°F.), yields a very efficient and rapid, all-purpose desiccant. It absorbs 6.6 percent of its weight and can be regenerated easily and repeatedly.

Miscellaneous Uses. - Calcined gypsum is used as a fireproof filling in the hollow walls of safes and filing cabinets, for surgical casts and orthopedic bandages, as an ingredient in the manufacture of match heads, and as a filler.



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## Building Uses

The most important uses of calcined gypsum are in the preparation of gypsum products for building purposes. Calcined-gypsum products are noted for their light-weight, fire-resisting, low-heat-conducting, sound-proofing, and vermin-proofing qualities. The following table[11] lists the results of tests on solid gypsum tile, 6 inches thick and 2 feet square, at the Underwriters' Laboratories, Inc., in 1911. The temperatures were taken on the unexposed face of the tile at definite intervals after the beginning of the test.

| Furnace temperature, °F. | Duration of fire, hours | | | | | |
|---|---|---|---|---|---|---|
| | Temperature on unexposed face, °F. | | | | | |
| | 1/2 | 1 | 1-1/2 | 2 | 3 | 4 |
| 1,000 | 81 | 82 | 92 | 104 | 129 | 161 |
| 1,300 | 80 | 83 | 94 | 113 | 146 | 178 |
| 1,600 | 80 | 85 | 100 | 121 | 168 | 185 |
| 1,900 | 73 | 80 | 100 | 129 | 179 | 189 |
| 2,200 | 77 | 86 | 108 | 144 | 186 | 208 |

Modern requirements for rapid building construction and for desirable and durable materials have greatly expanded the gypsum industry.

Gypsum Plasters. - The principal use of calcined gypsum is as a plaster for covering interior walls and ceilings of buildings. These wall plasters are prepared from calcined gypsum by adding a retarding agent to control the time of set and a binder to increase the cohesiveness of the plaster when it is made plastic with water. Wall plasters may be classified as neat, wood-fibered, ready-sanded, prepared-finish, molding, insulating, and acoustical plasters for interior use and as staff or stucco for exterior use.

Neat-gypsum plasters are also known as cement plasters. They consist of calcined gypsum, a fiber such as hair, a retarder, and other materials that add plasticity to the plaster. This type is mixed with 2 or 3 parts by weight of sand at the place of use and applied as the scratch and browning coats in plastering practice. Standard specifications (A. S. T. M. Designation C 28-30) for neat gypsum plaster require that not less than 60.5 percent by weight of the cementitious material shall be calcined gypsum ($CaSO_4.1/2H_2O$), that the tensile strength shall be not less than 150 pounds per square inch, and that when mixed with three parts by weight of testing sand it shall set in not less than 8 hours or more than 32 hours.

11/ Schweim, Henry J., Gypsum Partition Tile; Gypsum Association, 1928, p. 6.



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Wood-fibered plasters consist of calcined gypsum, wood fiber, retarder, and other materials that improve plasticity. They may be used with or without an equal weight of admixed sand for the scratch and browning plaster coats. This type is intended for use where sand is expensive or scarce or where an unusual toughness, light weight, and some flexibility of the finished wall or ceiling is desired. Standard specifications (A. S. T. M. Designation C 28-30) state that wood-fibered plasters shall contain not less than 60.5 percent by weight of calcined gypsum and not less than 1 percent by weight of wood fiber made from a nonstaining wood, that it shall set in not less than 1 1/2 hours or more than 8 hours, and that after setting it shall have a tensile strength of not less than 125 pounds per square inch.

Ready-sanded plaster is neat plaster to which the sand is added at the mill or mixing plant rather than on the job. It is intended for use in localities where suitable sand is expensive or scarce. The following standard specifications (A. S. T. M. Designation C 28-30) apply to gypsum ready-sanded plaster used for the scratch or first coat and for the browning or second coat.

| | Scratch coat | Browning coat | |
|---|---|---|---|
| Shall contain not more than | 66.66 | 75 | Percent by weight of sand. |
| Remainder shall contain not less than..... | 60.5 | 60.5 | Percent by weight of calcined gypsum. |
| Shall set between..... | 1-1/2 and 7 | 2 and 6 | Hours. |
| After setting shall have a tensile strength of not less than..... | 75 | 50 | Pounds per square inch. |

These three classes - neat, wood-fibered, and ready-sanded - may be broadly grouped by their uses as base-coat plasters.

Prepared gypsum finishing plasters are made of calcined gypsum, selected for color and specially prepared for use as the final plaster coat. Additions of plastic material such as clay or talc improve the working qualities. They may or may not be retarded and may require only the addition of water to be ready for application. This type of wall plaster may be subdivided into trowel-finish, which contains no sand; sand-float finish, which contains clean white sand; and gauging plasters, which should only be used when mixed with 2 parts by weight of dry hydrated lime. Standard specifications (A. S. T. M. Designation C 28-30) state that calcined gypsum for use as a finishing coat shall be classed in two grades - white and gray, that it shall all pass a



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No. 14 sieve and not less than 60 percent a No. 100 sieve, that it shall set when not retarded in 20 to 40 minutes and when retarded in not less than 40 minutes or more than 6 hours, and that its tensile strength after setting shall be not less than 200 pounds per square inch.

Specially colored gypsum finishing plasters are available to the trade in as many as 13 standard shades. They are prepared by adding pigments to the normal plasters.

Molding plasters for building purposes are intended for use in interior embellishments, cornices, moldings, and other ornamental plaster work. They are made from specially selected and prepared calcined gypsum and are ground much finer than other plasters so that the molds or casts will be unusually dense, hard, and durable and will present a smooth-finished surface free from pinholes or voids. Standard specifications (A. S. T. M. Designation C 59-30) state that gypsum molding plaster shall contain not less than 80 percent by weight of calcined gypsum, shall all pass a No. 30 sieve and not less than 90 percent a No. 100 sieve, shall set in 20 to 40 minutes, and shall have a tensile strength after setting of not less than 200 pounds per square inch.

Insulating plasters are specially prepared mixtures of calcined gypsum with other materials or chemicals that are added for their fire-resistant qualities or for attaining light weight in the finished product. Calcined gypsum mixed with asbestos fibers is used as an insulating cover on pipes and boilers. By a patent process certain chemicals are mixed with calcined gypsum to make an insulating plaster. When water is added these chemicals react and liberate a gas that expands the mass to several times its original bulk. As the set of the plaster is timed to take place near the period of greatest expansion the resulting mass is porous, light weight, and full of sealed cavities that act as insulators. A dry insulation product recently developed and sold under several trade names is made by passing scrap wallboard or lath through a hammer mill. The product is light and fluffy and is poured into the spaces to be insulated.

Acoustical plasters comprise mixtures of calcined gypsum with either chemicals, porous materials, or both. The chemicals react with the water after mixing and form minute interconnected cavities or cells, many of which break through to the surface before the plaster sets. The sound waves are trapped and absorbed in these small, winding passageways. Pumicite or volcanic ash is used as a porous, sound-absorbent material in acoustical plasters. It also acts as a trap for the sound waves. Plasters for acoustical uses are substituted for and applied in the same manner as the usual finish plaster coats.



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Staff or stucco is a gypsum plaster mixed with excelsior, manila, or other fiber. It is used for the exterior walls of temporary exposition or fair buildings. Additions of cement, glycerin, and dextrine to the staff yield compositions that fit it for massive statuary or smaller art objects and decorative panels.

Keene's Cement. - As now manufactured in the United States, Keene's cement is prepared from crude gypsum, selected for color and purity, by calcination at high temperature (595° C. or 1,100° F.) until all the chemically combined water is driven off and the material becomes anhydrous. This calcined product is finely ground, and accelerators of set, such as potash salts, or alum are added. The finished material has unique properties that distinguish it from the ordinary gypsum plaster. It will keep indefinitely, can be retempered (made plastic again) after the initial set has developed, possesses a high compressive and tensile strength, and will take a polish. It is used for hard-finish wall plasters, for making imitation marble, and for ornamental plaster work. Where high strength is not desired it is mixed with various proportions of lime putty and used for the finishing coat. Standard specifications (A. S. T. M. Designation C 61-30) for Keene's cement state that it shall all pass a No. 14 sieve, that not less than 98 percent shall pass a No. 40 sieve and not less than 80 percent a No. 100 sieve, that it shall set in 1 to 4 hours, that it shall have a tensile strength of not less than 450 pounds per square inch, and that it shall contain not more than 2 percent of combined water. Keene's cement was first introduced in England where it is made by calcining gypsum to the hemihydrate or first-settle stage, soaking in a solution of alum or borax, recalcining at about 480° C. (900° F.), and grinding to a fine powder. The names Mack's, Parian, Martin's, or Magand's cement are sometimes applied to products similar to Keene's cement. These various names are used to indicate the different chemicals or solutions used in the preparation of the material.

Estrichgips. - A special type of flooring plaster known as Estrichgips (sometimes termed "hydraulic plaster") is prepared by calcining lump gypsum under oxidizing conditions to a temperature of about 900° C. (1,650° F.). At this temperature some of the gypsum is decomposed to lime (CaO), which remains in the material, and sulphur dioxide ($SO_2$), which passes off. The quantity of lime in the final product ranges from 4 to 10 percent. Estrichgips has a very slow set and, with tamping, will form a dense, hard, durable mass that is resistant to wear. It is widely used as a flooring plaster in Germany, but so far it has not been used in the United States.

Calcined gypsum that contains fiber or wood shavings in the approximate proportion of 7 to 1 by weight is used for poured-in-place construction of floors and roofs of large buildings. The material is mixed in mixing boxes and poured on removable wooden forms or on



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gypsum- or fiber-board forms which are left in place. The construction is usually reinforced with either galvanized welded wire mesh or wire cables. The completed floor or roof deck is monolithic and may be covered with any type of material.

Gypsum Board. - The three general types of gypsum board now manufactured are lath or plasterboard, wallboard, and sheathing board. They are designed for different uses, but all consist essentially of a layer of gypsum plaster enclosed between sheets of slightly absorbent, fibrous, unsized paper. Gypsum boards can be cut and nailed as easily as lumber. The ingredients and method of manufacture on a continuous casting machine are similar for the three types. Calcined gypsum, to which sawdust, cork, starch, rosin-soap foam, or other filling material has been added, is spread on a soak belt and mixed by revolving fingers or spiders with water.

From the soak belt the mix falls into a spindle mixer where any remaining lumps are broken down. The spindle mixer is a horizontal, flat-bottomed bowl which contains a number of 6-inch rubber balls that are kept in constant motion by the rapidly revolving center shaft and ridged bottom. In the construction of board machines the present trend is to replace the soak belt with agitating mixers in which the calcined gypsum, water, starch, and foam are mixed before passing to the spindle mixer. The slurry from the spindle mixer is then transferred onto a horizontal layer of paper which is fed continuously to the machine. Rolls spread the wet plaster evenly over the paper to the desired thickness and place the second layer of paper on top of the plaster. Edgers, located just before the rolls, produced sealed, square, or round edges on the board by turning an overlap of the bottom paper to which the top paper is cemented by the rolls. This continuous strip of board is conveyed on a belt at such speed that the plaster will have set hard enough to permit handling by the time the cutting knife at the end of the belt is reached. Belt speed is usually between 50 and 60 feet per minute for board 3/8 inch in thickness. The speed depends upon the capacity of the drier and the type of board being produced. As the plaster sets, the minute needlelike crystals of gypsum penetrate the fibrous paper and form a very strong bond with it. The bond is made stronger by the starch added to the plaster slurry. The toothed knife cuts the board into strips of the desired lengths; these are then transferred mechanically on rolls to the drier, where they are completely dried by steam and are ready for use when discharged. On 3/8-inch board the drier removes approximately 900 pounds of excess water, the wet board weighing about 2,400 pounds and the dry board 1,500 pounds per thousand square feet. Nominal temperatures in the drier are 180° C. (360° F.) near the feed end, 100° C. (212° F.) at the middle, and 60° C. (140° F.) at the discharge end.

Gypsum lath or plasterboard is usually manufactured in 3/8-inch thicknesses and is intended for use as a strong, fireproof plaster



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base in place of wood or metal lath. It provides a uniform surface with an exceptionally strong bond for succeeding plaster coats and requires less plaster than other types of lath. Other advantages of its use are that it is easily and quickly erected, does not warp or buckle after the application of wet plaster, is verminproof, and increases the heat- and sound-insulating qualities of the finished wall. Specifications for gypsum lath (A. S. T. M. Designation C 37-34) state that the gypsum core may contain not more than 15 percent by weight of fiber; that the finished board shall have nominal thicknesses of 1/4, 3/8, or 1/2-inch, nominal widths of 16, 24, or 32 inches and nominal lengths of 32 or 48 inches and that the weight per 1,000 square feet shall be between 900 and 1,500 pounds for 1/4-inch thickness, 1,350 and 2,000 pounds for 3/8-inch thickness, and 1,800 and 3,000 pounds for 1/2-inch thickness.

A perforated plasterboard or lath is manufactured by drilling a number of holes (1/2 to 1 inch in diameter) in standard board after it is bundled. The holes provide a mechanical key for plaster coats. A new method of perforating lath is to stamp the holes by means of a patented machine while the lath is wet or dry. The most satisfactory results are obtained on dry lath which after discharge from the drier is fed continuously to the stamping machine. A special type of heat-insulating plasterboard is made by mounting a thin, bright sheet of aluminum foil on the back of standard board. The metal foil increases the insulating value of the plasterboard by reflecting the heat waves.

Gypsum wallboard is designed for use on interior walls, ceilings, or partitions without addition of plaster. The standard thickness manufactured is 3/8 inch. It has a surface suitable to receive final decoration, is fireproof and verminproof, does not expand or contract, is easy to install, and has good sound- and heat-insulating qualities. Some wallboard is made with a cellular gypsum core obtained by adding small quantities of chemicals to the calcined gypsum before mixing it with water. These chemicals react with the water to form gases which are trapped in small bubbles as the plaster sets. The cellular type of core increases the insulating qualities and the flexibility of the board. A. S. T. M. Standard Specifications for Gypsum Wallboard (Designation C 36-34) state that the gypsum core shall contain not more than 15 percent by weight of fiber; that the face of the board shall be true and free from imperfections that would render the board unfit for use with or without further decoration; that the nominal thicknesses may be 1/4, 3/8, or 1/2 inch, the nominal widths 32, 36, or 48 inches, and the nominal lengths from 4 to 12 feet inclusive; and that the weight per 1,000 square feet shall be between 900 and 1,500 pounds for 1/4-inch thickness, 1,350 and 2,000 pounds for 3/8-inch thickness, and 1,800 and 3,000 pounds for 1/2-inch thickness.

Select types of wallboard are made by special treatment of the board face or by mounting other materials on one of the surfaces. Thus, some wallboards are finished to simulate a ceramic tile wall or to



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resemble wood paneling. Wallboards also are available finished with a natural-wood veneer for paneling work or with aluminum foil to increase the heat-insulating value. Tongue and groove edges and recessed edges are recent improvements to wallboard.

Gypsum sheathing board consists of a gypsum core encased in a tough, fibrous covering, the outer surface and ends of which are moistureproofed. The usual thickness manufactured is 1/2 inch. It is used for sheathing on frame structures under shingles, stucco, or brick veneer, and as an exterior finish on temporary structures. Gypsum sheathing board is fireproof, moistureproof, and windproof; it is permanent and has good insulating qualities and superior strength. A. S. T. M. Standard Specifications for Gypsum Sheathing Board (Designation C 79-34) state that it shall have nominal thicknesses of 1/2 or 3/4 inch, nominal widths of 24 or 32 inches, and nominal lengths of 6 feet 8 inches or 8 feet and that the weight per 1,000 square feet shall be between 1,800 and 3,000 pounds for 1/2-inch board and 3,000 and 4,000 pounds for 3/4-inch board.

Gypsum Tiles and Blocks. - Gypsum tiles and blocks are made in various sizes and designs for flooring, roofing, furring, non-load-bearing partitions, and fireproof covering of columns, beams, and shafts. They are light in weight, fire-resistant, and sound- and heat-insulating, are readily laid, and can easily be cut with a hand saw. Gypsum tiles and blocks may be either solid or hollow (cored). They are made by casting a slurry of calcined gypsum, with or without a filler or aggregate, into molds on a continuous belt or slowly revolving wheel. After the gypsum has set sufficiently, the molds and cores, if used, are removed and the tiles passed through a drying machine from which they emerge ready for use. Some tiles are reinforced by casting the gypsum over metal fabric parallel to the face with rods parallel to the edges.

Roof and floor tiles are available either solid or hollow and in long or short spans. They are usually reinforced with metal fabric or rods or both and may be laid in place on T-shaped subpurlins or on the main purlins. Gypsum plank 2 to 3 inches thick, reinforced with wire mesh and metal tongue-and-groove edges, has been found satisfactory in roof and floor construction.

Partition tiles are obtainable either solid or hollow and in several thicknesses ranging from 2 to 8 inches. The usual width and length are 12 and 30 inches, respectively. Partition tiles are not reinforced and are used only in non-load-bearing walls. Because of their light weight and large uniform size, they are easily and quickly laid in gypsum mortar to yield an even surface ready for plasterwork. Partition tiles are widely used for partition, corridor, and fire-division walls, elevator and stairway enclosures, column and beam covering, and ventilating and heating ducts.



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Furring tiles are made hollow or solid in 1 1/2- and 2-inch thicknesses 12 inches wide and 30 inches long. They are secured to the wall with spikes or built-in wall ties.

Special gypsum-tile shapes, known as shoe, soffit, or angle tiles, are used in combination with 2- or 3-inch hollow partition tiles to form a fire-resistant cover for beams and girders.

Floor domes are molded hollow boxes or tiles of reinforced gypsum used as filler in concrete-floor construction. They effect a considerable saving in deadweight construction and yield a smooth surface on the ceiling below.

## USES OF ANHYDRITE

Anhydrite, because of its properties, does not lend itself to the great variety of uses for which gypsum is adapted, so that in this country it is regarded as an undesirable constituent of gypsum deposits if present in appreciable percentages. Aside from its use as a fertilizer it is little employed in the United States. In some foreign countries, however, considerable quantities are used for chemical processes and building products.

Fertilizer or Land Plaster. - Anhydrite can be used in place of gypsum for fertilizing purposes if it is finely ground to overcome its lower solubility in water. In 1936 approximately 40,000 tons of anhydrite were used as fertilizer for peanut crops in the eastern United States, for which it has proved very satisfactory.

Cement Retarder. - The use of anhydrite as a cement retarder has been investigated extensively, and two reports[12] covering the subject have been issued by the Bureau of Mines. The investigations by Roller and Halwer were more complete than those covered by the earlier report and substantiated Berger's general conclusions. Following is a brief summary of the later report.

Anhydrite, used alone, has a definite effect but is less effective than pure gypsum as a set retarder. About four times as much pure anhydrite as pure gypsum of equal fineness is required to produce the same retardation. However, if the same quantity of $SO_3$ is added, anhydrite-gypsum mixtures may be as effective a retarding agent as gypsum. The quantity of anhydrite that can be used safely in admixture with gypsum varies up to 50 percent and depends upon the total $SO_3$ added and the susceptibility of the clinker to retardation, which is governed by the amount of water vapor absorbed by the clinker. With constant addition of $SO_3$, anhydrite substituted for

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12/ Berger, E. E., Calcium Sulphate Retarders for Portland Cement Clinker: Tech. Paper 451, Bureau of Mines, 1929, 35 pp.
Roller, P. S., and Halwer, M., Relative Value of Gypsum and Anhydrite as Additions to Portland Cement: Tech. Paper 578, Bureau of Mines, 1937, 15 pp.



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gypsum generally causes a small decrease in 1:3 mortar strength. At 28 days the decrease in both tensile and compressive strengths amounts to 2 percent and appears to be independent of the quantity of anhydrite admixed with gypsum between 25 and 75 percent.

Anhydrite is a more-suitable raw material than gypsum in the chemical and high-temperature processes used in the manufacture of sulphides, sulphates, lime, and portland cement. It contains a higher percentage of the essential $SO_3$ and conserves heat because there is no water of hydration to be driven off as there is with gypsum. In England, at Billingham, County Durham, a thick deposit of anhydrite is worked at a depth of about 800 feet and used as a raw material for the manufacture of ammonium sulphate, sulphuric acid, and cement. It is reported that considerable anhydrite is used in France and Germany in similar chemical processes.

Calcination has little or no effect on anhydrite because it contains no water of hydration and when used alone has none of the properties of calcined gypsum that would adapt it to use as a building material. Experiments[13] have shown that anhydrite can be hydrated to gypsum in a relatively short time by fine grinding and mixture with water. After hydration in this manner the material may be calcined to form building plasters.

Numerous investigations to utilize anhydrite for building plaster by the addition of other substances that act as accelerators of set have been more successful than the hydration process. The results show that the addition of certain inorganic salts or combinations of these salts to ground anhydrite will yield plasters that have a quick set with resulting density and tensile strength comparable to those of calcined-gypsum plasters. The accelerators or catalyzers may be added either in the dry state during grinding or as a solution in the mixing water. A patented anhydrite plaster has been commercially successful in England since its introduction in 1929. It is prepared by grinding crude anhydrite, with additions of 2 percent or less by weight of potassium and zinc sulphates, in a tube mill to a fineness of about 15 percent retained on a 170-mesh sieve. This plaster has a small water requirement and good plasticity, attains a final set in 50 to 70 minutes, and is used neat for the finishing coat. It is not suitable for base-coat work, as the sand-carrying capacity is low. Partition tiles are made from the anhydrite plaster by adding other chemicals that react with the mixing water, evolving $CO_2$ gas that aerates the mass before setting begins. The mix is poured in molds and passed through a drier to yield tiles that weigh 55 pounds per cubic foot and are suitable for non-load-bearing partitions. Another commercial product made from this anhydrite plaster is a colored

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13/ Farnsworth, Marie, The Hydration of Anhydrite: Ind. and Eng. Chem., vol. 17, no. 9, 1925, p. 967.



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aggregate wall plaster. It consists of colored anhydrite plaster as the binding agent and an aggregate (1/8 inch in diameter) of the same material that previously has been set, dried, and granulated. The mixture is troweled on the wall in the usual manner and after setting is rubbed to a smooth finish and waxed.

A recent United States patent (2090625) covers a high-temperature process for the transformation of anhydrite into a hydraulic cementitious material. Gypsum or anhydrite may be used as the raw material, but anhydrite is preferred because it requires less heat. The process consists of mixing ground anhydrite or gypsum (through 80-mesh) with not more than 2 percent by weight of phosphoric acid and sodium phosphate and not more than 3 percent by weight of silica or silicates. This mixture is made into pellets in a tumbling drum and then calcined at 980° to 1,260° C. (1,800° to 2,300° F.) in a tunnel kiln. The clinker is ground and catalyzed with a set accelerator, usually a mixture of potassium and zinc sulphates. The initial set of the product may be controlled so as to take place in 1 to 2 hours and the final set within 4 hours. The product is claimed to have good plasticity, high sand-carrying capacity, low water-cement ratio, and a tensile strength when set of 600 to 1,200 pounds per square inch and to yield a dense, hard, water- and acid-resistant finished material. Laboratory studies have been followed by pilot-plant production.

Tests have also shown that anhydrite would be satisfactory as a filler in certain grades of paper, as an insecticide diluent, for the manufacture of salt cake, and for flux in certain metal-smelting processes.

## DEVELOPMENT OF DEPOSITS

Gypsum and anhydrite occur as bedded deposits with large lateral and relatively small vertical dimensions. Anhydrite, which has limited use in the United States, must be treated as an impurity in a gypsum deposit. Therefore anhydrite deposits will not be considered in this section, although they would be amenable to the same considerations and development methods. As commercial gypsum deposits are widely distributed in the United States several important factors should be considered before any development work is done. Studies of the potential market and its area, and the productive capacity already in the area are necessary to determine whether the production can be assimilated. In most sections of the country the market for gypsum and its products is limited by the nearness of other plants and by freight rates. Other factors are the location of the deposit with respect to transportation and its adaptability to low-cost operating methods.



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## Prospecting

The purity and extent of the deposit should be proved by adequate sampling and drilling or trenching so that the available tonnage of commercial material may be calculated by multiplying the length, width, and thickness in feet by 145 pounds (approximate weight of 1 cubic foot of gypsum) and dividing by 2,000. Exploratory drilling may be performed satisfactorily by the diamond, churn, or air drill, any of which will provide enough information.

## Quarrying

The proper method of development (open-cut or underground mining) is determined by the thickness and attitude (flat or inclined) of the gypsum beds, the type and thickness of overburden, and the topography of the region. Open-cut mining or quarrying is preferred when the gypsum beds are flat-lying or nearly so and have little or no overburden. If the overburden consists of unconsolidated material, such as soil or glacial debris, a greater thickness may be removed economically than if the overburden is consolidated material, such as shale or limestone. This overlying material is removed as far as possible by mechanical stripping (dragline or shovel), followed by hand stripping to clean out irregularities on the top of the gypsum deposit. The overburden is either cast back onto the quarry floor or is hauled to refuse dumps. In some operations where the cover is light the overburden and gypsum are shot down together and separated on the quarry floor. Holes for primary blasting are drilled by churn or air drills the full depth of the bench in a line parallel to and a predetermined distance back of the face. Low-strength dynamite and black blasting powder are the explosives generally used. After the gypsum is broken loose by the primary blast, block-holing or secondary shooting is done to reduce the large blocks to at least one-man size. The broken material is then loaded by hand or mechanical means into cars for transportation to the mill.

Gypsite deposits always lie close to the surface and usually have little or no overburden. As the material is soft and friable it requires no blasting and is worked with power shovel or scraper.

## Mining

Where the gypsum beds have a heavy overburden or are inclined so that operations must be carried beneath an increasing thickness of cover, underground methods are usually employed. Underground mining is successful only if the roof is strong enough to require a minimum of timbering. Mine entries are drifts or adits, slopes, or vertical shafts. The room-and-pillar system of mining is common practice on horizontal or slightly pitching beds, but steeply pitching beds are worked by the drift and shrinkage-stoping methods. About 75 percent



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of the gypsum is extracted in the first mining by the room-and-pillar method which is generally carried to the property limits before any pillars are pulled. Pillar and roof extraction or second mining is carried on the retreat, recovering as much gypsum as possible before the unsupported roof caves. Total recovery should be about 90 percent.

Drills are of two types, an electric-powered rotating drill using an auger bit and a percussion air drill. According to report undercutting machines are unsatisfactory because the cuttings tend to clog the cutter bars. The rock is broken loose with low-strength dynamite and loaded into mine cars. In vertical-shaft mines the gypsum is raised to the surface by skips, automatic dumping cages or bucket elevators. In adit or slope mines it is raised by belt or pan conveyors, or cable haulage.

## BYPRODUCT GYPSUM

Manufacturers of chemicals in the United States produce large quantities of hydrated calcium sulphate which constitutes a major waste-disposal problem at some plants. Most of this gypsum is produced in the manufacture of phosphoric acid and phosphate chemicals by treating rock or bone phosphate with sulphuric acid. Approximately 1 ton of precipitated gypsum slurry is obtained per ton of phosphate rock treated.

About 1925 several chemical plants began to utilize this waste material, coverting it into various gypsum products. Recovery of the precipitated gypsum is relatively simple. After the gypsum is separated from the parent liquor it is washed and treated with sodium carbonate or bicarbonate to neutralize any remaining traces of phosphoric or other acids. The resulting slurry is dewatered by filtering or centrifuging and is then suitable for calcining and processing in the usual manner. By this method the precipitated gypsum, formerly considered a waste material, has been converted into a valuable byproduct.

## PROCESSING

Modern preparation of gypsum for manufacture into calcined products may be divided into the following stages: Crushing and grinding, calcining, regrinding, and mixing. These steps and the various types of machinery used are outlined on the generalized flow sheet (fig. 1). Most of the machinery is standard and is not designed primarily for the gypsum industry. The machines especially adapted to gypsum processing are the calcining kettles and the feeding and conveying equipment for finely ground and calcined gypsum. However, the physical character of gypsum varies from place to place, and care must be taken to select the most suitable equipment.



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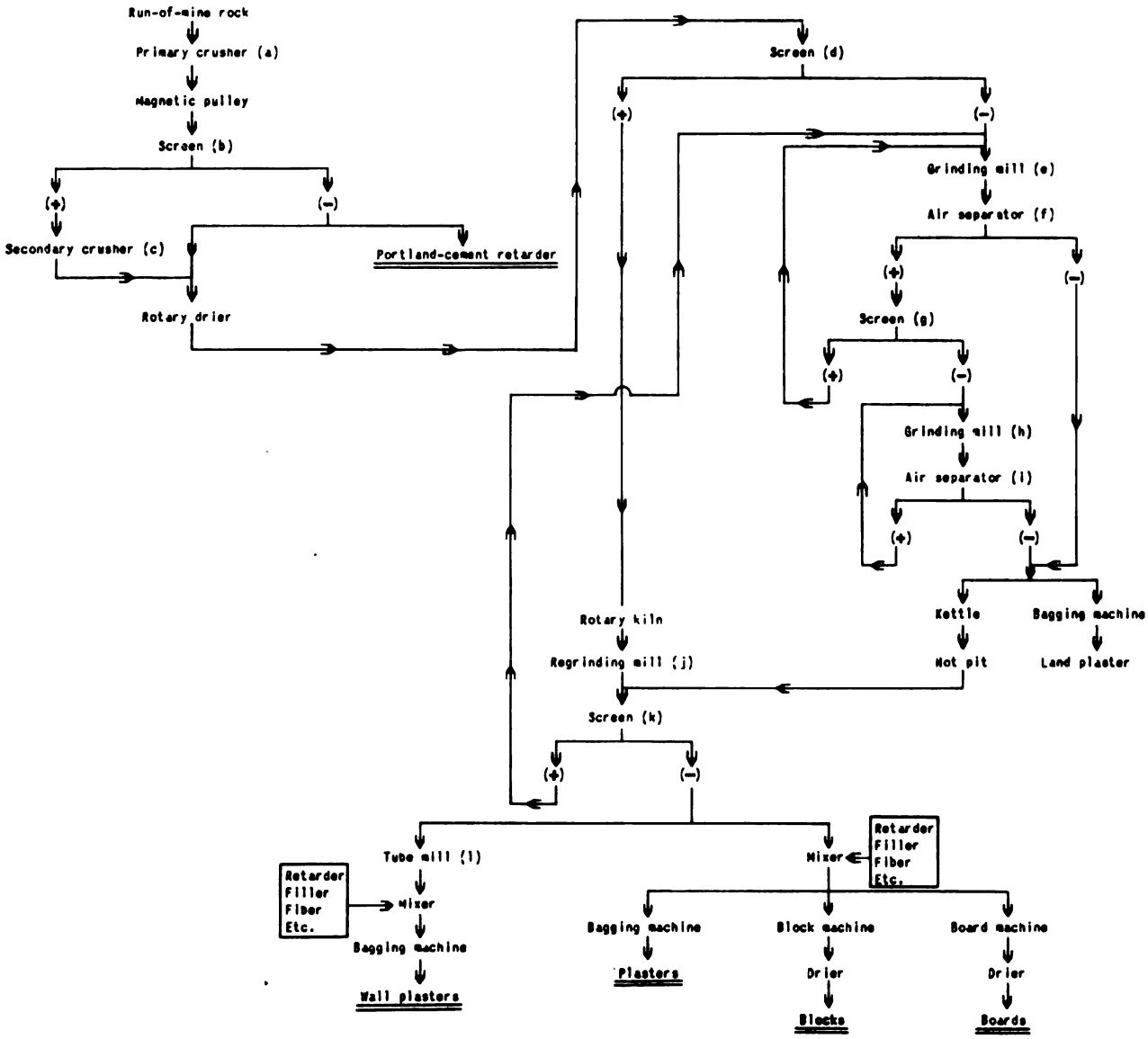


Figure 1.- Generalized flow sheet of a combined kettle and rotary-kiln gypsum-processing plant: (a) Rigid-hammer, gyratory, jaw, or single-roll types (set is about 3 inches if secondary crushers are used; if not, set is about 1 1/2 inches); (b) about 1 1/2-inch openings, reel, inclined, or vibrating types; (c) roll, ring, or cracker types setting about 1 1/2 inches (in recent installations the secondary crushing stage and the preceding screen are eliminated and the material goes directly from the primary crushers to the drier); (d) about 9-inch openings, vibrating type; (e) swing-hammer, ring-roller, Buhr, or emery types, setting about 3/8 inch; (f) separation at 100-mesh; (g) vibrating type, 1/8-inch openings; (h) roller mill; (i) integral with roller mill (discharge is 70 to 95 percent through 100-mesh); (j) swing-hammer, ring-roller, Buhr, or emery types; (k) vibrating type, 10- to 20-mesh; (l) gravity-flow, ventilated, or air-swept types.

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## Crushing and Grinding

In recent years crushing and grinding machines have been perfected to eliminate secondary crushing. Impact mills, such as the swing- or rigid-hammer type, and ring-roller crushers are used successfully where run-of-mine rock does not exceed one-man size. These mills reduce the run-of-mine material to minus 1 1/2 inches or smaller, which is suitable-size feed for rotary kilns. Fine-grinding machines have also been improved so as to handle larger feed and reduce it to smaller size than formerly. Buhr and emery mills, which in the past were favorites for fine grinding in the gypsum industry, are rapidly being discarded for the more efficient, high-capacity modern mills. Rotary crushers or "crackers" similar to the familiar coffee mills which were used widely in the industry in the past are also being replaced by impact-type mills.

A combination drying and grinding mill, which is used to some extent in certain industries, has been tried in the gypsum industry where it appears to have possibilities. This mill, which is directly connected with an air separator, utilizes the waste heat from the calcining process and dries and grinds the crude gypsum in one operation. Further application of the principle of drying and grinding in one operation resulted in experimental hammer-type mills in which the temperature was raised sufficiently to calcine as well as grind the gypsum. Thus one operation would replace four conventional stages - drying, grinding, calcining, and regrinding. The product of these experimental grinding-calcining mills is said to be suitable for many of the uses of calcined gypsum made in the usual manner.

Little trouble is experienced in conveying and elevating crude gypsum with standard handling equipment until the fine-grinding stage. However, as the finely ground product tends to "flood" or "gush," screw and drag-chain conveyors installed in close-fitting pipes are used to convey and feed the material to the bins or calcining kettles. The use of air separators has eliminated the need for some conveying equipment in gypsum plants.

## Calcining

The calcining process, accomplished by kettle or rotary kiln in a gypsum plant, is the stage during which part of the water of crystallization is removed from the raw gypsum and the hemihydrate is produced.

### Kettles

Calcining kettles are peculiar to the gypsum industry. They consist of a cylindrical steel shell 3/8 to 1/2 inch thick, having a diameter of 8 to 15 feet and a depth of 6 to 14 feet. Popular sizes are 10 by 8, 10 by 10, 12 by 10, and 14 by 12 feet. The bottom of the



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kettle is a one-piece, convex, steel plate 1 to 3 inches thick, placed so that the convex surface is inside the kettle. Sectional bottoms made by bolting together 6 to 15 triangular segments are not as satisfactory as one-piece bottoms except in the larger kettles. On the top or cover plate there is a trap for charging raw gypsum and a vent pipe to conduct the dust and evolved steam to a dust collector. For efficient heating, horizontal flues 8 to 14 inches in diameter extend through the kettle from side to side. There are usually four flues, arranged in parallel pairs one above the other or set in one plane. To prevent overheating, the gypsum is agitated constantly by horizontal rabble arms or sweeps attached to a vertical gear-driven shaft in the center of the kettle. Two sets of rabble arms are commonly used, one equipped with drag chains below the flues near the bottom and the other just above the flues. The discharge gate or spout of the kettle is at the bottom of the side wall. Figure 2 shows the construction of the gypsum kettle.

The kettle is set over the firebox, resting on a heavy iron lip ring which is supported on a firebrick foundation. The firebrick masonry extends upward and surrounds the kettle, leaving an annular space of 12 to 16 inches between the brick and the kettle shell. This flue space is provided with baffles that direct the heat, applied at the bottom of the kettle, around the shell and through the horizontal flues before it passes out of the stack.

A hot pit is built directly under the discharge spout of each kettle. It is constructed with a sloping bottom so that the calcined gypsum will flow freely to the screw conveyor at the lower side of the pit. The hot pit is provided with a well-fitted cover in which a flue permits the escape of steam, thus preventing condensation in the pit.

In the kettle process finely ground raw gypsum is run continuously through the charging gate until the kettle is full. Loading requires from 10 to 15 minutes and is done directly after the kettle has been emptied of its previous charge. During loading, the kettle temperature drops from about 170° C. (340° F.) to approximately 110° C. (230° F.). The temperature then rises slowly to 120° C. (250° F.), at which point the gypsum appears to boil vigorously and emits steam rapidly. This apparent boiling is caused partly by mechanical agitation of the rabble arms but chiefly by released water of crystallization in the form of steam which, as it escapes upward tends to float the fine particles of gypsum. The temperature remains virtually the same until the boiling becomes more subdued then rises at an increasing rate. Between 150° and 165° C. (300° and 330° F.), boiling ceases, little or no steam is given off, and the contents of the kettle have settled to 10 to 14 percent less than the original volume. This quiet period indicates that most of the gypsum particles are dehydrated to the hemihydrate. Heating is continued until the contents of the kettle register about 170° C. (340° F.), at which temperature they are discharged into the hot pit.



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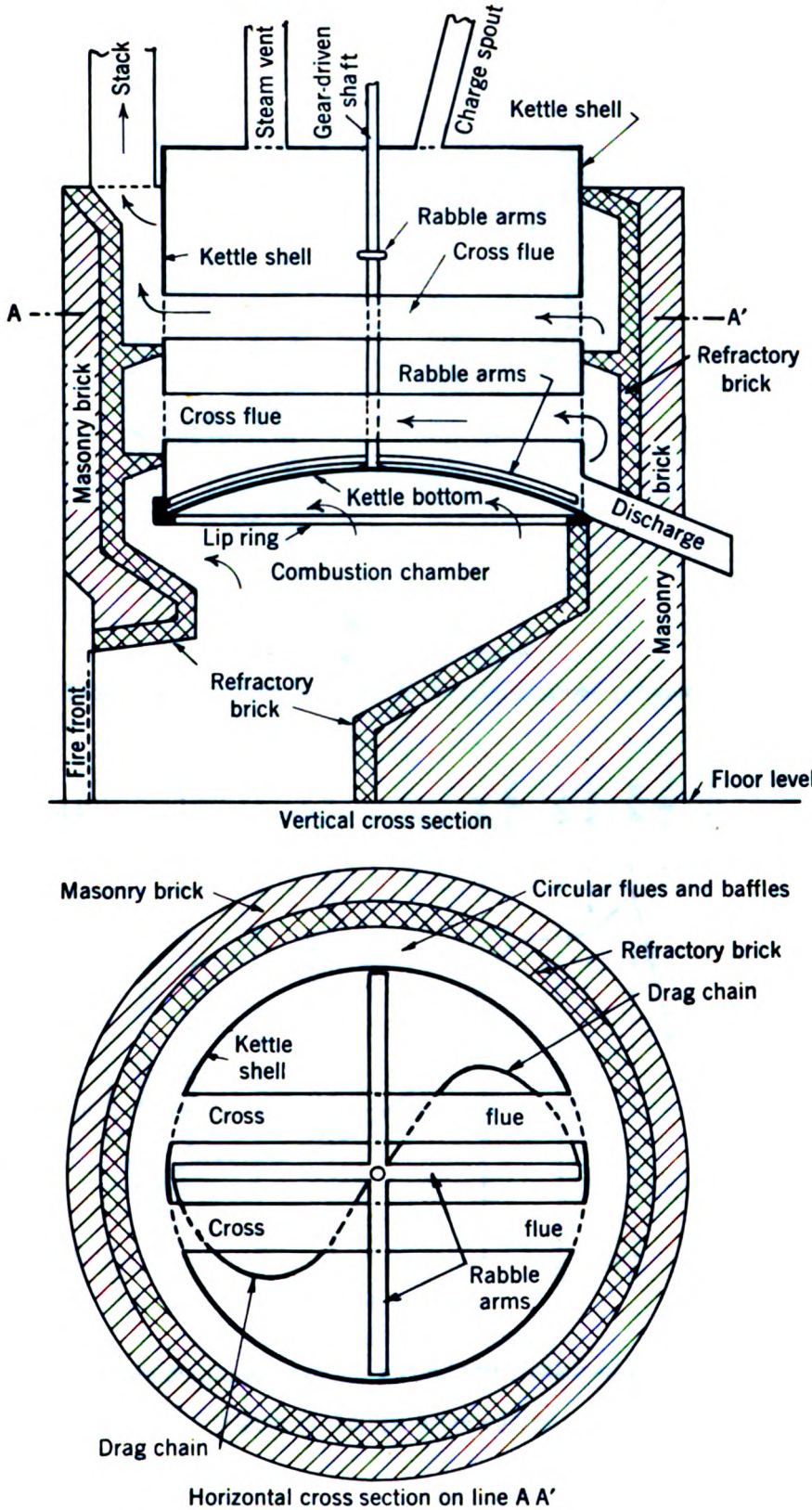


Figure 2 – Generalized sections of a calcining kettle.

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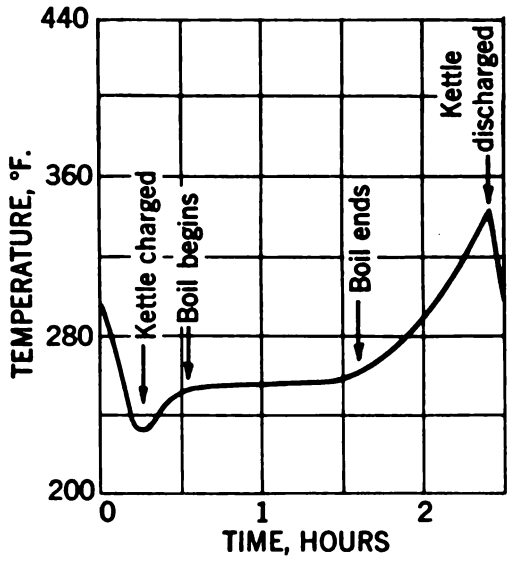
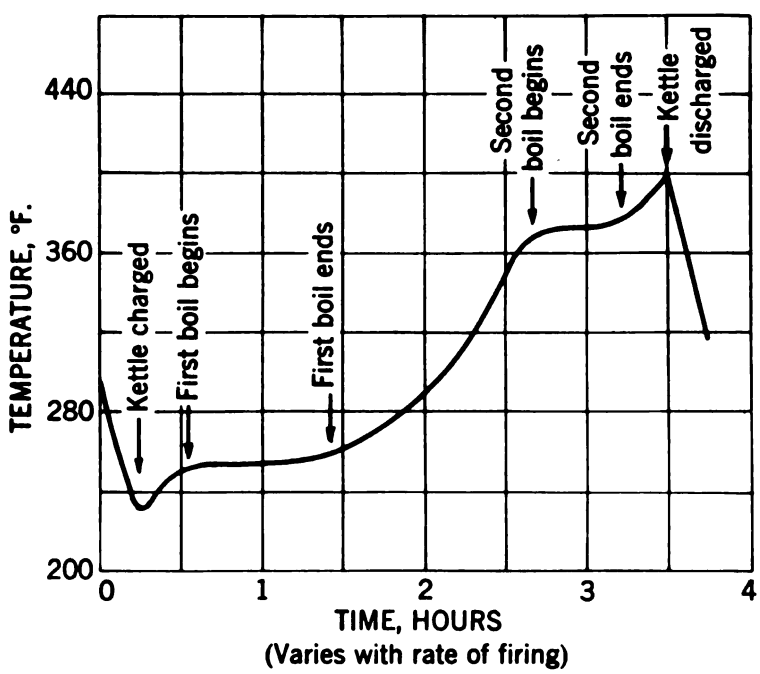



Typical temperature curve for first-settle calcined gypsum




Typical temperature curve for second-settle calcined gypsum

Figure 3.–Temperature curves.

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The discharge temperature at different mills ranges from 160° to 175° C. (320° to 350° F.). Calcined gypsum at this stage is known as "first-settle" calcined gypsum. It contains from 5 to 6 percent water and is employed for wall plasters, board, block, and most of the common uses of calcined gypsum. The time required to calcine a kettle of raw gypsum to "first-settle plaster" ranges from 1 to 3 hours at different plants, depending chiefly on the rate of firing, the fineness and purity of the raw gypsum, and the kettle size and design.

To obtain "second-settle" calcined gypsum the kettle contents are heated beyond the "first-boil" and "first-settle" stages. At about 175° C. (350° F.) the gypsum again starts to boil and give off steam. This "second boil" is of shorter duration and less vigorous than the "first boil" because a smaller percentage of water of crystallization is removed. It reaches maximum activity at 190° C. (370° F.), at which point the temperature remains constant until the boiling activity begins to decline. The temperature then rises until at 200° C. (390° F.) boiling has ceased and no steam is given off. At this stage the contents of the kettle have lost 15 to 18 percent of their original volume. Heating is continued until the temperature reaches 200° to 210° C. (390° to 410° F.), then the kettle is discharged. The product, which contains less than 1 1/2 percent water when fresh, is known as "second-settle" calcined gypsum. This material has less plasticity but greater density and strength than first-settle plaster. It is used for molding, pottery, casting, and special plasters. At present little second-settle calcined gypsum is manufactured because material with the same qualities is obtained by specially treating first-settle calcined gypsum as explained under "Aging plasters". Figure 3 shows the general temperature changes for first- and second-settle calcined gypsum.

The procedure for calcining gypsite in kettles differs somewhat from that for calcining rock gypsum because of the impurities and high free-moisture content of the gypsite. Charging is done slowly in batches of 1/4 to 1 ton with enough time between batches to allow the material in the kettle to reach the "first-boil" stage. This process, which prevents the agitators from sticking, is continued until the kettle is full. A long period of calcination (3 to 8 hours) is required for gypsite. In discharging it is customary to leave a prime of 1/2 to 1 ton of calcined gypsite in the kettle to protect the hot kettle bottom from the wet raw charge.

In the kettle process accurate control of calcination is maintained by means of recording thermometers and visual observation. This close control, aided by the pulverization of raw gypsum, results in a uniform calcined product, despite the fact that the calcining is done by a discontinuous process.



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As kettles are adaptable to the calcination of all types of rock gypsum and gypsite they are used in all sections of the country and are the principal type of calcining equipment. In 1937 there were 179 kettles in operation in the United States.

## Rotary Kilns

Gypsum calcination in rotary kilns is a continuous process that utilizes crushed raw gypsum (under 1 1/4 inches) as contrasted with the batch process, which uses pulverized gypsum in kettles. The first rotary kilns used to calcine gypsum were of the Cummer type, consisting of a steel cylinder 30 to 40 feet in length and 4 to 5 feet in diameter, supported on a slight angle by extended trunnions at either end. The cylinder is enclosed in brick walls and is heated externally and internally from below by a furnace and flues; the latter extend the full length of the kiln. Rock gypsum crushed to 3/4 inch is fed into the high end of the slowly revolving cylinder. Longitudinal lifting blades cascade the gypsum so that all surfaces of the fragments are subjected to heat in the short time required for passage through the cylinder. The furnace gases heat the outside of the shell and enter the calcining chamber through a series of ports in the cylinder shell. Calcining temperatures are between 205° and 315° C. (400° and 600° F.). The discharge goes directly to bins where it remains about 36 hours, during which time the heat of the material completes the calcination of the larger fragments. Four bins are required for continuous operation of one kiln. The Cummer-type kilns were never widely used in the United States.

The modern type of rotary kiln is similar to that used for burning portland cement and lime. In the gypsum industry it consists of an end-fired cylindrical tube 70 to 155 feet in length and 6 to 8 feet in diameter. The more recent installations are near the maximum length and diameter given. The kiln, which is supported with a slight pitch, is fed from the high end. Inside the kiln spiral flights are provided in the first 10 feet at the feed end to prevent the feed from piling up and spilling over the end. Low, longitudinal diaphragms for about one-third to one-half of the length break up the rock stream and prevent stratification or segregation of the rock according to size. The kiln is lined with firebrick at the firing end for one-fourth to one-third of its length.

As gypsum calcination is, relatively, a low-temperature process, direct firing of the fuel into the rotary kiln results in incomplete combustion and contamination of the gypsum with unburned fuel. This condition is avoided by the use of an outside combustion chamber at the end of the kiln. Complete combustion of the fuel takes place in the chamber, and only the hot gases enter the cylinder and come in direct contact with the gypsum. The rotary kiln may be fired from either end, but preferred practice is to fire from the discharge end



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of the kiln to effect a counterflow of gypsum and hot gases. This arrangement is more efficient with regard to fuel consumption than the parallel-flow method of firing from the feed end of the kiln.

Rock gypsum for rotary-kiln feed is crushed to about 1 1/4 inches or smaller. Preferred practice is to size this material further by removing the fines, although some plants make no separation by sizes after crushing. The gypsum passes through the kiln in approximately 45 minutes and is discharged at a temperature of 160° to 195° C. (320° to 380° F.), counterflow firing. In the early installations the kilns discharged into hot pits where final calcination of the large fragments took place. Present practice is to send the discharge directly from the kiln to grinding mills where the calcination is completed.

The quantity of dust picked up by the hot gases depends upon how heavily the kiln is forced and whether or not the fine material is removed from the raw feed. In natural-draft kilns a simple dust chamber at the base of the flue stack recovers most of the dust, which may be returned immediately to the kiln discharge.

Temperature in the rotary kiln is controlled by two pyrometers, one in the flue gases as they leave the kiln and the other in the discharge stream of calcined gypsum.

In 1937 there were 15 end-fired rotary kilns in operation in the United States. This type of kiln with its high capacity, low labor costs, low grinding costs, and relatively low fuel and power requirements is widely used on gypsum mined in New York and on imported gypsum. It has also been adapted successfully to the softer gypsum of the Middle West and to high-temperature calcination of gypsum to produce material suitable for the manufacture of Keene's cement. An ideal plant set-up would include a combination of rotary kiln to calcine coarse material and kettles to calcine fine material.

## Beehive Kilns

The only other type of gypsum-calcining equipment employed in the United States at present is a beehive kiln used for the manufacture of Keene's cement. It consists of a circular base 20 to 30 feet in diameter, surmounted by a low dome that makes the kiln 12 to 16 feet high. The kiln is heated by several furnaces or combustion chambers that are operated independently of each other. The hot gases are conducted to the top of the kiln by flues on the inner wall, then down through the gypsum and out of the kiln by flues and an underground conduit to a stack. Selected lump rock gypsum 6 to 10 inches in diameter is heated at white heat for 3 to 5 days, after which the calcined lumps are crushed, ground, screened, and pulverized. In 1937 there were four kilns of this type in operation.



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Fuel used in the various types of gypsum-calcining equipment may be coal, fuel oil, or natural gas, depending upon which will furnish the lowest-cost B.t.u. value. When coal is used in end-fired rotary kilns it is usually pulverized and injected into the combustion chamber by an air current.

## Regrinding

Calcined gypsum, obtained by kettle calcination, is in a pulverized condition when discharged into the hot pit. It is removed from the hot pit by screw conveyors as soon as possible because hot-pit storage accelerates the set, lowers the plasticity and water ratio, and increases the density of "first-settle" plaster. After the calcined gypsum leaves the hot pit, it passes over a vibrating screen from which the undersize goes to the mixing plant, and the oversize is either reground or returned to the kettle feed. In some plants the hot-pit discharge is not screened or reground but is conveyed directly to storage bins or to the mixer.

Calcined gypsum discharged from rotary kilns is sent directly to regrinding mills (swing-hammer, roller, ring-roller, or buhr-stone types). In these mills calcination of the larger fragments of calcined gypsum is completed, and the material is thoroughly mixed to yield a product of uniform quality and characteristics. The discharge of the regrinding mills may be screened and treated similarly to the kettle-calcined gypsum, or it may be sent directly to the mixing plant.

## Tube Milling

The regrinding of calcined gypsum in tube mills was first applied about 1911 but was not generally accepted until after 1929. Tube milling increases the bulk, plasticity, and sand-carrying capacity of calcined gypsum. With the Emley plasticity machine it has been found that the plasticity of calcined gypsum before tube milling (150 to 180) will be increased to a figure between 250 and 350 after tube milling. This type of regrinding is widely used on all ordinary wall plasters in which high bulk, plasticity, and sand-carrying capacity are desirable. It usually is not applied to calcined gypsum which is intended for manufacture of gypsum board or block or certain specialty plasters. Tube-milled plaster will not mix readily or uniformly with lime putty and should not be used for gauging plaster.

Feed to tube mills should be constant and should have a relatively low temperature, that is, below 80° C. (180° F.). The rate of feed may be determined roughly as 1 ton of calcined gypsum per hour for every 2 tons of balls in the mill. Balls of 1- to 1-1/8-inch diameter appear to be most effective. The most-efficient temperature of the mill discharge is reported to be about 115° C. (240° F.).



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## Aging Plasters

Plasters that require a minimum of water for mixing and setting are desired for casting, molding, gauging, dental, and orthopedic uses. These products are less plastic but more dense than the common gypsum plasters, have greater strength, and have a minimum of voids in the set product. Formerly "second-settle" calcined gypsum was used to obtain the desired properties, but in present-day practice the same qualities are obtained by aging or treating "first-settle" material. To age calcined gypsum it is only necessary to expose the material to air for a period. Artificial aging is accomplished by introducing a predetermined quantity of a chemical salt, such as calcium chloride into the kettle during calcining. This process affords close control of the degree of aging and is said to yield a more uniformly aged plaster than natural processes.

## Mixing

Calcined gypsum, as delivered to the mixing hopper, will set within 6 to 35 minutes after the addition of water. Thus, to render the material suitable for commercial use, certain substances are added to regulate the time of set, to act as fillers, and to serve as binders while the gypsum is in the plastic state.

### Retarders

Retarders of set are added to calcined gypsum to slow the initial set within a desired time range which is determined by the intended use. Several substances may be used to prolong the time of initial set, the more common of which are glue, starch, slaughter-house tankage, clay, sugar, and gums. Commercial retarder, in general use at present, is a colloid prepared by treating hair, leather scraps, or refuse from stockyards with lime and caustic soda. Retarders are effective by slowing the rate of growth of the gypsum crystals as they form from solution, by temporarily taking up part of the water and later releasing it, or by decreasing the rate of solubility of the hemihydrate in the mixing water.

The amount of retarder that may be added to calcined gypsum ranges up to 15 pounds per ton, depending on climatic conditions and the purity and intended use of the calcined gypsum. Casting and similar plasters require little or no retarder. Finishing plasters contain 1 to 3 pounds of retarder per ton, and fibered and unfibered wall plasters may contain 4 to 15 pounds per ton. Gypsite plasters, because of their high clay content, need only small amounts of retarder. In hot climates or in the summer less retarder is required than in cold climates or in the winter.



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## Accelerators

Accelerators of set are substances that will speed the set of gypsum plasters by serving as nuclei for the growth of the gypsum crystals or by directly increasing the rate of growth of the crystals. Raw gypsum is a powerful accelerator, especially when added to cold calcined gypsum. Gypsum plaster that has been set and later reground is widely used. Other common accelerators are potassium sulphate, alum, and salt. Casting, molding, dental, and orthopedic plasters usually require the addition of accelerators. In these plasters the accelerator is added dry at the mill.

For emergency additions of retarders or accelerators on the job the most satisfactory method is to dissolve the material in the water to be mixed with the gypsum plaster. This method insures even distribution of the retarder or accelerator, which is necessary to obtain an even set.

## Fibers

Hair, wood, asbestos, sisal, or similar vegetable fibers are added to gypsum plasters intended for base-coat work. They do not increase materially the strength of the finished wall but are of temporary benefit in serving as a binder to the plaster while it is in the plastic state and preventing flowage and waste of the material back of the lath. For this purpose 3 to 6 pounds of hair per ton of plaster are sufficient. Sisal or other fibers are used widely in place of the more expensive hair. Between 25 and 50 pounds per ton of soft nonstaining wood fibers, such as willow or poplar, are added. The wood fibers also serve as a filling agent, increasing the bulk and decreasing the weight of the plaster.

## Fillers

Granulated cork, wood shavings, sawdust, etc., are added to calcined gypsum chiefly to decrease the weight and improve the heat- and sound-insulating qualities of the finished product. They are added to calcined gypsum intended for manufacture into gypsum board and block. The sand added to sanded plaster for the scratch and browning coats must be classed as a filler, although three parts of sand may be used for each part of gypsum plaster. Other material, such as clay or talc, may be added to improve the plasticity of wall plasters.

## Mixing

In the mixing operation a weighed quantity of calcined gypsum, usually 1 ton, is placed in a hopper built directly over the mixing machine. Weighed quantities of retarder or accelerator, fiber, and filler are then added to the calcined gypsum, and the contents of the hopper are discharged into the mixing compartments. The various



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ingredients are thoroughly mixed by being agitated by two sets of paddles attached to two parallel horizontal shafts that rotate rapidly in opposite directions. The mixing time should be not less than 1 minute.

The mixed product is then discharged directly to the packer, where it is placed in containers (barrels, cloth sacks, or paper sacks) for distribution. For sacking of plasters, cloth or paper sacks of the multiwall valve type are used. They are filled by automatic packers directly connected with the mixing compartment.

## PRODUCTION STATISTICS OF GYPSUM AND GYPSUM PRODUCTS

Gypsum has been used in the United States since the latter part of the eighteenth century, when crude gypsum was imported from Nova Scotia for use as land plaster. Deposits were known to occur in central New York as early as 1792 and were quarried for agricultural gypsum shortly thereafter. As the population moved westward the deposits of other States were discovered and utilized. The calcination of gypsum to produce building plasters is said to have begun in the United States about 1835. This phase of the gypsum industry developed very slowly at first because of the crude calcining methods used and the difficulty of introducing a product that, although not new, was comparatively unknown and necessitated changes in the methods of application. After 1898 gypsum wall plasters began to be used extensively and the gypsum industry expanded rapidly until the World War period, when there was a short-lived decline. During the war the usefulness of gypsum lath and wallboard was clearly demonstrated by their satisfactory use on buildings constructed for war purposes. Thus, after 1918 the general acceptance of these products stimulated the gypsum industry which, aided by a building-construction boom, reached its highest levels in 1925 and 1926. The high rate of production declined only slightly until 1930 but then fell rapidly until 1933. Since that time recovery in the gypsum industry has been relatively slow because of the general lag in all types of building construction.

Table 1 shows the quantity of crude gypsum mined and imported and the apparent crude supply in the United States from 1880 through 1937. Although imports of crude generally increased in tonnage from 1888 to 1915, domestic crude production increased so rapidly that the relative importance of the imported material declined. The disruption of shipping facilities during the World War caused the imported tonnage of crude gypsum to drop sharply through 1918. Imports did not recover to pre-war levels until about 1922, when they were of less importance to the gypsum industry than in previous normal times. However, from 1925 to 1929, inclusive, the quantity of crude gypsum imported rose while domestic production declined. This upward trend in the percentage of crude imports was caused chiefly by the erection



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of several large new gypsum-processing plants along the Atlantic seaboard in New England and the Middle Atlantic States. These plants, established at strategic points for distribution of their output, use only crude Canadian gypsum. The uptrend in percentage of imported crude material has continued to the present time but appears to be approaching stability for the present capacity of processing plants in the country.

## Production by States

From its beginning in New York, the domestic production of crude gypsum has spread to many sections of the United States. In 1937 crude gypsum was mined or quarried in 17 States at 58 operations, which included 29 underground mines, 24 quarries, and 5 combinations of mine and quarry. New York, Michigan, Iowa, and Texas are the leading gypsum-producing States. Table 2 shows production of crude material by States from 1931 to 1937, inclusive. In addition to the States listed, New Mexico and Oregon have produced gypsum in past years.

## Sales

The increasing degree of fabrication, greater variety of products, and greatly increased proportion of the apparent crude supply that is processed into finished calcined products are the chief factors contributing to the more-or-less steady rise in the total value of all gypsum products (uncalcined and calcined) sold or used in the United States.

Table 3 shows the tonnages and sales value (f. o. b. plant) of gypsum products sold or used in the United States from 1927 to 1937, inclusive. The quantity of crude gypsum charged into calcining equipment is only a rough approximation obtained by deducting sales of raw gypsum from the apparent crude supply. However, this represents the best available data. The tonnage of calcined gypsum produced (kettle and kiln output) is available only for 1935 and 1937, when production was 1,383,093 and 2,411,362 tons, respectively.

Increased coverage by the Bureau of Mines canvass for 1937, which includes several gypsum-processing companies and plants utilizing by-product gypsum, necessitate adjustment of the 1937 data on calcined gypsum products sold or used so that they will be comparable with data for previous years. After such adjustment, made by eliminating production of companies included for the first time in the 1937 canvass, calcined gypsum products sold or used in 1937 were 2,500,643 tons (gross weight of products) valued at $34,622,651. The adjusted figure for the total value of all gypsum products (uncalcined and calcined) sold or used in 1937 is $36,543,357.



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## World Production

Gypsum deposits occur in many countries of the world, and because of the abundance and low price of gypsum that will not support long transportation charges, together with competition from other commodities, its production and consumption are chiefly local. The United States, France, United Kingdom, Germany, Canada, and the U. S. S. R. are the leading producing countries. The industry in the United States is unique in that it imports (from Canada and Mexico) considerable quantities of crude gypsum for processing into finished products. In the United Kingdom, France, Germany, and the U. S. S. R. some gypsum and anhydrite are consumed for the manufacture of sulphuric acid, sulphates, sulphides, and cement. In the United States production depends largely upon the volume of building construction. Table 4 shows production by countries during recent years.



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TABLE 1. - Mine production, imports, and apparent supply of crude gypsum in the United States, 1880-1937

| Year | Mine production, short tons | Imports, short tons | Apparent supply | | Year | Mine production, short tons | Imports, short tons | Apparent supply | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Short tons | Imports, percent | | | | Short tons | Imports, percent |
| 1880 | 90,000 | 1/134,766 | 2/228,000 | 59.1 | 1910 | 2,379,057 | 415,321 | 2,794,378 | 14.9 |
| 1881 | 85,000 | 1/144,040 | 2/229,000 | 62.9 | 1911 | 2,323,970 | 389,874 | 2,713,844 | 14.4 |
| 1882 | 100,000 | 1/143,788 | 2/255,000 | 56.4 | 1912 | 2,500,757 | 412,697 | 2,913,454 | 14.2 |
| 1883 | 90,000 | 1/176,793 | 2/270,000 | 65.5 | 1913 | 2,599,508 | 447,383 | 3,046,891 | 14.7 |
| 1884 | 90,000 | 1/186,267 | 2/258,000 | 72.2 | 1914 | 2,476,465 | 369,214 | 2,845,679 | 13.0 |
| 1885 | 90,405 | 1/131,220 | 2/233,000 | 56.3 | 1915 | 2,447,611 | 336,856 | 2,784,467 | 12.1 |
| 1886 | 95,250 | 1/136,942 | 2/241,000 | 56.8 | 1916 | 2,757,730 | 254,131 | 3,011,861 | 8.4 |
| 1887 | 95,000 | 1/164,313 | 2/265,000 | 62.0 | 1917 | 2,696,226 | 240,269 | 2,936,495 | 8.2 |
| 1888 | 110,000 | 175,501 | 285,501 | 61.5 | 1918 | 2,057,015 | 50,653 | 2,107,668 | 2.4 |
| 1889 | 267,769 | 191,481 | 459,250 | 41.7 | 1919 | 2,420,163 | 171,733 | 2,591,896 | 6.6 |
| 1890 | 182,995 | 191,844 | 374,839 | 51.2 | 1920 | 3,129,142 | 282,486 | 3,411,628 | 8.3 |
| 1891 | 208,126 | 123,488 | 331,614 | 37.2 | 1921 | 2,890,784 | 266,796 | 3,157,580 | 8.4 |
| 1892 | 256,259 | 202,836 | 459,095 | 44.2 | 1922 | 3,779,949 | 409,475 | 4,189,424 | 9.8 |
| 1893 | 253,615 | 184,016 | 437,631 | 42.0 | 1923 | 4,753,448 | 448,129 | 5,201,577 | 8.6 |
| 1894 | 239,312 | 182,000 | 421,312 | 43.2 | 1924 | 5,042,629 | 519,627 | 5,562,256 | 9.3 |
| 1895 | 265,503 | 215,655 | 481,158 | 44.8 | 1925 | 5,678,302 | 634,423 | 6,312,725 | 10.0 |
| 1896 | 224,254 | 201,901 | 426,155 | 47.4 | 1926 | 5,635,041 | 824,081 | 6,459,522 | 12.8 |
| 1897 | 288,982 | 182,785 | 471,767 | 38.7 | 1927 | 5,346,888 | 828,619 | 6,175,507 | 13.4 |
| 1898 | 291,638 | 185,994 | 477,632 | 38.9 | 1928 | 5,102,250 | 1,028,816 | 6,131,066 | 16.8 |
| 1899 | 486,235 | 220,168 | 706,403 | 31.2 | 1929 | 5,016,132 | 1,036,385 | 6,052,517 | 17.1 |
| 1900 | 594,462 | 235,067 | 829,529 | 28.3 | 1930 | 3,470,393 | 902,358 | 4,373,751 | 20.6 |
| 1901 | 633,791 | 263,428 | 897,219 | 29.4 | 1931 | 2,559,017 | 713,880 | 3,272,897 | 21.8 |
| 1902 | 816,478 | 342,011 | 1,158,489 | 29.5 | 1932 | 1,416,274 | 374,072 | 1,790,346 | 20.9 |
| 1903 | 1,041,704 | 297,873 | 1,339,577 | 22.2 | 1933 | 1,335,192 | 359,490 | 1,694,682 | 21.2 |
| 1904 | 940,917 | 329,547 | 1,270,464 | 25.9 | 1934 | 1,536,170 | 360,186 | 1,896,356 | 19.0 |
| 1905 | 1,043,202 | 399,230 | 1,439,432 | 27.7 | 1935 | 1,903,880 | 450,250 | 2,354,130 | 19.1 |
| 1906 | 1,540,585 | 436,999 | 1,977,584 | 22.1 | 1936 | 2,712,510 | 661,595 | 3,374,105 | 19.6 |
| 1907 | 1,751,748 | 453,911 | 2,205,659 | 20.6 | 1937 | 3,058,166 | 897,484 | 3,955,650 | 22.7 |
| 1908 | 1,721,829 | 300,158 | 2,021,987 | 14.8 | | | | | |
| 1909 | 2,252,785 | 350,160 | 2,602,945 | 13.4 | | | | | |

1/ Imports for fiscal year ended June 30.
2/ Estimated for calendar year.

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TABLE 2. - Crude gypsum mined in the United States, 1931-37, by States, in short tons

| State | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 |
|---|---|---|---|---|---|---|---|
| California.... | 90,899 | 49,997 | 57,175 | 55,620 | 70,408 | 142,853 | 186,158 |
| Colorado..... | (1/) | (1/) | (1/) | (1/) | 17,610 | 27,424 | 28,586 |
| Iowa..... | 321,627 | 178,087 | 172,555 | 180,271 | 230,203 | 344,221 | 387,255 |
| Michigan..... | 383,123 | 248,542 | 211,392 | 281,033 | 342,989 | 496,611 | 553,242 |
| Nevada..... | 131,079 | 80,938 | 74,249 | 82,348 | 106,894 | 167,342 | 160,347 |
| New York..... | 744,613 | 347,153 | 363,745 | 391,408 | 485,792 | 609,204 | 700,357 |
| Oklahoma..... | (1/) | (1/) | 97,008 | 105,620 | 125,177 | 156,545 | 159,639 |
| Texas..... | 239,391 | 110,360 | 112,106 | 138,326 | 179,783 | 257,773 | 280,807 |
| Utah..... | 22,178 | (1/) | (1/) | (1/) | (1/) | 40,275 | 46,197 |
| Other States2/ | 626,107 | 340,142 | 246,962 | 301,544 | 345,024 | 470,262 | 555,578 |
| | 2,559,017 | 1,355,219 | 1,335,192 | 1,536,170 | 1,903,880 | 2,712,510 | 3,058,166 |

1/ Included under "Other States."

2/ 1931: Arizona, Colorado, Kansas, Montana, Ohio, Oklahoma, South Dakota, Virginia, and Wyoming.
1932: Arizona, Colorado, Kansas, Montana, Ohio, Oklahoma, South Dakota, Utah, Virginia, and Wyoming.
1933-34: Arizona, Colorado, Kansas, Montana, Ohio, South Dakota, Utah, Virginia, and Wyoming.
1935: Arizona, Kansas, Montana, Ohio, South Dakota, Utah, Virginia, and Wyoming.
1936-37: Arizona, Idaho, Kansas, Montana, Ohio, South Dakota, Virginia, and Wyoming.

TABLE 3. - Domestic and imported crude gypsum calcined and gypsum products sold or used in the United States, 1927-37

| Year | Crude gypsum calcined, short tons1/ | Gypsum products sold or used | | | | |
|---|---|---|---|---|---|---|
| | | Uncalcined | | Calcined | | Total value |
| | | Short tons | Value | Short tons2/ | Value | |
| 1927.. | 5,102,829 | 1,072,678 | $2,846,410 | 4,498,091 | $46,217,634 | $49,064,044 |
| 1928.. | 5,010,315 | 1,120,751 | 2,351,280 | 4,447,305 | 37,791,589 | 40,142,869 |
| 1929.. | 4,903,139 | 1,149,378 | 2,428,758 | 4,182,317 | 37,038,713 | 39,467,471 |
| 1930.. | 3,290,645 | 1,083,106 | 2,277,404 | 2,839,538 | 33,377,067 | 35,654,471 |
| 1931.. | 2,421,454 | 851,443 | 1,882,557 | 2,132,386 | 26,838,107 | 28,720,664 |
| 1932.. | 1,274,210 | 516,136 | 1,216,388 | 1,193,761 | 16,576,918 | 17,793,306 |
| 1933.. | 1,203,409 | 491,273 | 1,089,100 | 1,060,471 | 14,555,112 | 15,644,212 |
| 1934.. | 1,317,409 | 578,947 | 1,266,945 | 1,140,590 | 16,184,459 | 17,451,404 |
| 1935.. | 1,759,000 | 595,130 | 1,329,140 | 1,552,968 | 22,358,005 | 23,687,145 |
| 1936.. | 2,543,422 | 830,683 | 1,865,673 | 2,210,338 | 31,088,885 | 32,954,558 |
| 19373/ | 3,094,825 | 860,825 | 1,920,706 | 2,645,081 | 36,914,006 | 38,834,712 |

1/ Theoretical tonnage representing the difference between the apparent crude gypsum supply and the total sales of uncalcined gypsum products.

2/ Total weight of finished calcined products which includes the added weight of filler, fiber, paper, and reinforcing.

3/ Includes tonnages and values of products made from byproduct gypsum. Adjusted figures comparable with earlier years are: Gypsum products sold - calcined, 2,500,463 tons with value of $34,622,651; total value, $36,543,357. (See text.)



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TABLE 4. - World production of gypsum, 1932-36, by countries, in metric tons

| Country 1/ | 1932 | 1933 | 1934 | 1935 | 1936 |
|---|---|---|---|---|---|
| Algeria | 90,550 | 86,220 | 83,920 | 56,710 | 45,265 |
| Argentina 2/ | 33,543 | 34,805 | 44,142 | 49,773 | 55,706 |
| Australia | 54,822 | 61,547 | 91,093 | 119,933 | 127,610 |
| Austria 3/ | 36,000 | 45,000 | 45,000 | 46,000 | 47,000 |
| Brazil 4/ | 2,000 | 2,000 | 2,000 | 2,000 | 2,000 |
| Canada | 398,883 | 336,283 | 447,507 | 510,266 | 763,049 |
| Chile | 11,989 | 15,204 | 10,901 | 26,151 | 22,556 |
| China | 64,508 | 64,020 | 67,720 | 4/68,000 | 68,800 |
| Cyprus 5/ | 10,995 | 12,881 | 9,217 | 14,851 | 16,603 |
| Egypt | 236,795 | 238,721 | 149,713 | 190,666 | 256,211 |
| Estonia | 8,299 | 5,670 | 4,905 | 6,238 | 13,849 |
| France | 2,081,010 | 1,689,050 | 1,453,450 | 1,275,000 | (6/) |
| Germany 7/ | 398,500 | 485,000 | 810,000 | 855,000 | (6/) |
| Greece | 2,167 | 3,535 | 4,525 | 3,612 | 13,779 |
| India, British | 52,246 | 33,674 | 47,507 | 46,045 | 55,277 |
| Irish Free State | - - - | - - - | - - - | - - - | 6,096 |
| Italy | 529,827 | 534,026 | 458,978 | 471,167 | 324,789 |
| Japan | (6/) | (6/) | (6/) | 127,633 | 137,677 |
| Latvia 5/ | 36,812 | 48,251 | 81,816 | 98,935 | 123,503 |
| Luxemburg | 9,403 | 12,864 | 10,689 | 29,474 | 29,110 |
| Mexico | 61,795 | (6/) | (6/) | 54,514 | 61,711 |
| Morocco, French | 39,080 | (6/) | (6/) | (6/) | (6/) |
| New Caledonia | 11,900 | 11,565 | 13,585 | - - - | - - - |
| Palestine | 1,481 | 2,602 | 3,431 | 4,543 | 6,209 |
| Peru | 6,553 | 7,000 | 8,147 | 9,056 | 12,560 |
| Portugal | 4,385 | 7,492 | 20,315 | 4,800 | 6,850 |
| Rumania | 40,018 | 57,094 | 47,176 | 62,018 | 45,991 |
| Spain | 697,230 | 709,246 | 741,245 | (6/) | (6/) |
| Sweden | 115 | 49 | 121 | 170 | 93 |
| Tunisia | 26,000 | 17,580 | 15,550 | 11,000 | 11,200 |
| Union of South Africa | 7,113 | 11,809 | 23,296 | 21,590 | 31,962 |
| U.S.S.R. | 493,000 | 474,000 | 688,000 | (6/) | (6/) |
| United Kingdom | 1,011,440 | 1,000,865 | 977,014 | 997,673 | 1,018,562 |
| United States | 1,284,815 | 1,211,259 | 1,393,583 | 1,727,162 | 2,460,735 |
| Yugoslavia | (6/) | 8/ 842 | (6/) | (6/) | (6/) |
| | 7,800,000 | 7,400,000 | 7,900,000 | 8,300,000 | 9,400,000 |

1/ In addition to countries listed, gypsum is produced in Cuba and Switzerland, but production data are not available.
2/ Rail and river shipments.
3/ Estimates furnished by Bundesministerium für Handel and Verkehr.
4/ Approximate production.
5/ Exports of crude and calcined gypsum.
6/ Data not available; estimate included in total.
7/ Data supplied by Deutscher Gips-Verein, E. V., Berlin, Germany. Data exclude rock gypsum mined and used by cement, paint, and other plants from their own quarries.
8/ Serbia only.

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